Illinois Climate: Trends, Impacts and Issues

PROCEEDINGS OF THE 12TH ANNUAL ENR CONFERENCE

Urbana-Champaign, Illinois
September 13-14, 1983

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Energy and Natural Resources

James R. Thompson, Governor
Michael B. Witte, Director

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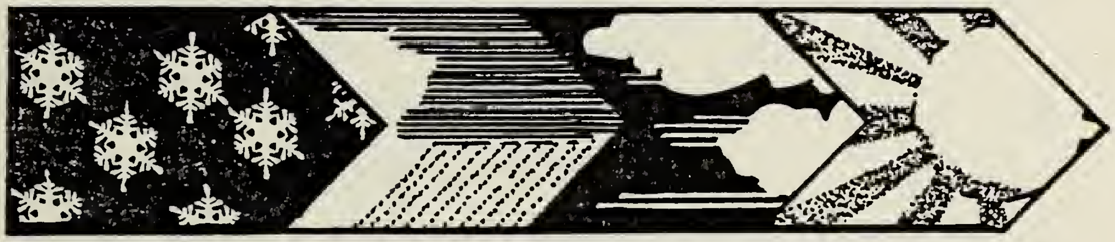

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Illinois Department of Energy and Natural Resources

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FOREWORD

Climate change, its causes, and its effects on man, agriculture and environmental quality provided the theme for the 1983 ENR conference entitled "Illinois Climate: Trends, Impacts and Issues." This was the 12th in a series of annual meetings sponsored by the department focusing on energy and natural resource issues relevant to Illinois.

Social, political, economic and scientific aspects of climate and climate change were examined during the meeting, beginning with a review of Illinois' climate during the past 10,000 years up to the present. Differing theories on future climate were offered, and the keynote speaker addressed the impacts of climate variations on public and private decision makers.

The second half of the conference examined research relating to climate, particularly how climate influences migration of agricultural pests and the controversial issues of increasing carbon dioxide levels in the atmosphere and acid deposition in North America.

In addition to the papers presented at the conference, this document also contains biographical data on the speakers.

WELCOME ADDRESS

Michael B. Witte, Director
Illinois Department of Energy and Natural Resources

Welcome to the 12th Annual Conference of the Department of Energy and Natural Resources. This year's conference is entitled "Illinois Climate: Trends, Impacts and Issues" and it represents a slight departure from our conferences of the past. We have tended to focus in the past almost exclusively on policy considerations, be the issue water or energy or hazardous waste. The climate of this conference will tend to be slightly more academic. As we shall see, though, there are tremendous practical implications and very exciting potential applications of the knowledge being shared here during this two-day period.

I think this can be seen simply by looking at today's Chicago Tribune. I don't know how many of you saw it, but the lead story on the front page says "Summer Heat and Drought to Cut Corn Crop by 48 Percent." The article goes on to point out that the soybean crop will be cut by one-third nationally. What that article did not say, unhappily for Illinois, is that in contrast to the nation as a whole, which will lose about 48 percent of its corn crop, Illinois will lose 60 percent of its corn crop this year. So it's clear that short-term variations in climate and weather can have a tremendous impact on human activity.

I won't dwell on that now, but tomorrow in my remarks I hope to return to the importance of improving our predictive capability for dealing in some more aggressive way with the technology of modification.

My assignment this morning is really more limited. It's one of a welcome to you, so just let me say the following. First, to our attendees, welcome and I am sure that you will find the next two days both enjoyable and rewarding. Second, to our speakers, including the speakers from within the Department, I am pleased and honored to be able to attract speakers of such clear national and international reputations to share your knowledge and your insights with us over the next two days. To the University, thank you very much for hosting us. And finally to those who could not attend the conference today, the weather is beautiful - wish you were here!

CLIMATES OF THE PAST, PRESENT AND FUTURE OF NORTH AMERICA

Helmut E. Landsberg
University of Maryland

Climate: Is it changing or isn't it? With apologies to Shakespeare, that is the question. Climate makes the headlines when the weather misbehaves. That has happened in recent years but not more frequently, as is often averred, than in earlier decades. Think back 50 years. A few of you may remember the "Dust Bowl." It was a miserable drought period and many farmers on the Great Plains were forced to leave their land and migrate. We have had milder repetitions of drought since and I am not sticking out my neck too far by suggesting that it will happen again. It has afflicted other parts of the country at other times: 1963 in the East, 1977 in the West. In this context let me point out to you that North America's climate cannot be viewed in isolation from the general atmospheric circulation of the globe. It all hangs together and North America is only 4.8 percent of the earth's surface.

Drought is part and parcel of the climate. In 1973 it struck the Sahel, now it prevails in Ethiopia. And there have been devastating floods, violent winds, traffic-stopping snowfalls and bone-chilling winters. They are all weather events, the sum-total of which make up the climate - together with all the benign and uneventful weather which we do not remember.

The general public gauges these events, not like the professional climatologist in terms of temperatures, precipitation or windspeed, but rather in terms of deaths, injuries, damages, and cost to the taxpayer for rehabilitation. That means people equate climate with climatic impact. These impacts are generally governed by population density. As the population has greatly increased in recent decades the exposure to climatic insults has also notably risen. It is not only the instantaneous catastrophes that cause trouble but there are the slower and more insidious effects on crops. When climatic vagaries hit the breadbasket there is in many parts of the world progression from malnutrition to starvation.

While untoward weather events have pushed climate to the forefront, there is no answer to the question whether or not climate has changed. To be sure, the global climate is not static. Locally it is only a fixed part of the landscape as is topography. We all know that in the course of geological history there have been notable climatic changes. It is well established that as recently as 18,000 years ago - a short time in geological terms - there was a major glaciation. Much of northern Europe, Canada and the north-central United States was covered by huge ice sheets. The global temperature was about 5 to 7°C (9 to 13°F) lower than at present. About 11,000 years ago we emerged from this ice age. An interglacial period set in. Rapid warming gave a global temperature about 1-1/2° (3°F) higher than presently. This so-called climatic optimum lasted from about 8,700 to 5,200 years before the present (Kearny & Luckman, 1983).

Since that time climate has fluctuated on all time scales: annually, decennially, centennially and millennially. All the evidence available to us does not indicate any discernible one-sided trends. There are intervals of lower or higher temperature and lower or higher precipitation. There is very little order in their sequence. They present what climatological jargon calls a "noise pattern."

Over the past 300 years we have had some numerical material to analyze these patterns from readings of thermometers, barometers, rain gauges and anemometers. In North America the oldest such records go back 250 years. Let me call your attention to the fact this time span is barely 3 percent of the time that had elapsed since the last ice age. And such longer instrumental observations are available from only a very few locations. Only in the last 100 years has there been a reasonable coverage of weather and climate stations, both globally and in North America. A great many deductions have been drawn from that short period of observations. Are these deductions solid or shaky? I shall attempt an answer to this question.

Let me point out first that climatologists have accepted, initially reluctantly but with more enthusiasm lately, observations other than instrumental as less precise, but still acceptable evidence, witnesses of past climates. These are labelled "proxy data." Many of them come from the organic world, some from the physical world and some from the "eye witness accounts of human history." As any evidence, these pieces of information have to be evaluated and it must be established how they corroborate each other. In some instances the various types supplement each other. I can illustrate this only briefly.

Best known among our silent witnesses are tree rings. These represent the annual increments of tree growth which respond to the antecedent and contemporary temperature and precipitation conditions. They can be readily dated for living or recently felled trees by counting. For early segments this can be done approximately by ^{14}C dating. Comparison of the ring-widths in recent years can be compared with parallel meteorological observations and a "transfer function" can be established. This will permit interpretations in terms of weather for growth rings for years prior to the start of meteorological observations. This permits fairly reliable estimates.

More general, both in terms of timing and meteorological range, are pollen analyses. These use pollen frequencies found in various horizons of cores of lake beds and permit us to establish the local plant associations. Clearly, at times when oak and maple pollen were present the climate must have been different from periods with birch and spruce pollen or those when grasses were prevalent. Many North American pollen assemblies have been analyzed.

Offshore with even a coarser time resolution, cores taken near our Atlantic coasts, we can resurrect other witnesses. These are the shells of plankton. Isotopic analyses of the oxygen locked in these shells are a measure of the sea-surface temperature at the time these animals lived. The oxygen ratio $^{16}O/^{18}O$ can also be established from ice cores in glaciers. Reliability of dating can be impaired in that information by some erasures in Nature's notebook.

What do we have in terms of historical information? At the outset it must be said that archeological information contributes relatively little to the store of climatic information. Of course, it tells us that there were people in certain localities. Their clothing, if preserved, is indicative of the climatic character and so are food remnants. But what happened when a site was abandoned? Migrations have often been interpreted as indicative of climatic changes, but this is a very uncertain conclusion. Resource depletion, disease and hostile action may also lead to abandonment of domiciles.

That leaves then the recorded history. There is a fairly abundant source of information on major catastrophes in Europe and in the Far East. Also, a lot of records exist on dates of blooming and harvest, flooding and low river stages, freezing dates of rivers and lakes. Advances and retreats of mountain glaciers were noted and permit inferences of climatic fluctuations. There are even systematic weather diaries back to the 14th century in some places. In the Western Hemisphere we lack such material. The Indians did not leave us any such records. Thus, the earliest weather information in North America is post-Columbian.

Hurricanes were then as prevalent as now. Even Columbus encountered one on his voyages (Brooks, 1941). Wrecks of Spanish galleons are the silent witnesses of these storms for which there is a fairly good chronology since (Ludlum, 1963). On land there are only sporadic weather notes. A reasonably authentic reoprt of a tornado was noted by a British sailor on an overland trek in 1569 (Hakluyt, 1589). But not until the 17th century is there much useful climatic information on the continent. The Pilgrims gave some indications of the climate on Cape Cod, from which one can infer that the early 17th century there was not much different from what it is presently.

The same can be gathered from the first report on Maryland in 1635 by the Reverend Andrew Whyte. We read in his account that the summer is hot there as in Spain and that winters have frost and snow but are short. He also describes a weather wind rose with south winds bringing heat and thunderstorms; north and northwest winds, cold and snow in winter; east and southeast winds, rain. The comparison with Spanish summers is very apt. Recent summer temperatures in Madrid have been averaging 23°C (73°F) with a maximum of 39°C (102°F). In Annapolis the mean summer temperature is 24°C (75°F) and the maximum also 39°C. The first systematic observations of weather were made in 1644-45 for one year by the chaplain of the Swedish garrison in what is now Wilmington, Delaware (Havens, 1955). Such short records are only indicative but do not seem to reveal any extraordinary departures from present conditions.

Good sources of information are records on inland and marine shipping. There are many available on the Dutch navigation on the Hudson River which give us dates of freezing and thawing for the route between New York and Albany. From these one can draw some inferences on winter conditions. It has also been possible to relate the sailing times of ships of the Hudson Bay Company to the ice conditions in the Bay (Catchpole & Faurer, 1983). There is still much unexploited information on wind and weather locked in ship logs. These may throw further light on the weather of North America. Similarly unexploited are reports of Spanish governors of Mexico, California, Florida and

the Gulf coast to their government and of missionaries in these areas to the Vatican. Only in the 18th century, starting with 1731, are there instrumental records in the East. In the early 19th century sporadic reports from the West became available, first from the Lewis and Clark expedition (Coues, 1965). Later, from about 1819 onward, regular observations became more common from military posts such as St. Louis, MO (1827; Blodgett, 1857), Ft. Winnebago, WI (1820; Wahl, 1868), Ft. Snelling, MN (1819; Baker, 1960), Ft. Vancouver, OR (1829; Forry, 1842).

What do all the instrumental and proxy data tell us about climate? The answers to this question must be approached with caution. Only about 500 years of such data are at hand and nearly all of it is from the Northern Hemisphere. The pre-instrumental as well as the instrumental data show cold and warm intervals but over longer intervals of time, say a century, there are about the same number of very cold months in winter and hot months in summer. These extreme months are sometimes bunched but their overall frequency is what one would expect in a statistical ensemble of that length of time. The same applies to precipitation. As a record lengthens, a new extreme will occasionally appear, but the more one studies these records, the more one finds evidence for compensation for a larger excursion in one direction soon to be followed by an equally large one in the opposite sense.

Much effort has been expended to find regularities in the climatic sequences. There has been much hunting for hidden periodicities. This is usually done by a statistical technique called "power spectrum analysis." It permits establishment of how much of the variances in a particular time series of observations is contributed by a particular period. One soon finds that we do not deal with regular periods which repeat precisely. There are, however, some rhythms in the records that occur with some regularity. None of these contributes very much to the total variance. Among them is one rhythm, apparently worldwide, of somewhat above two years, called the quasi-biennial oscillation. Its cause is not fully known. There appears also a rhythm of 5 to 7 years in length. It may have its origin in a southern hemispheric pressure fluctuation between the eastern and western Pacific Ocean. This seems to have global repercussions. It has been related to anomalous ocean currents off the coast of South America and rainfall regimes there. It also seems to have relations to the intensity of the Indian monsoons, and even to North American winter conditions.

Much has been written about solar activity as a cause for climatic fluctuations. The results of work along this line have been disappointing. The solar rhythms are somewhat irregular as evidenced by the sunspot numbers. Although their index shows an approximate 11-year fluctuation, claims of climatic rhythms of the same length are difficult to substantiate and at best contribute only a few percent of the variance. The double sunspot rhythm of 21 to 22 years (Hale cycle) appears to be more commonly reflected in time series of temperature, starting in 1659 in central England (Mason, 1976). It has also been found in a study of drought frequency in the western U.S., based on 300 years of tree ring indices (Mitchell, Stockton and Meko, 1979). It is hoped that this presently ambiguous relation can be based on a solid footing in a few years when enough data on solar energy flux have accumulated from satellite observations.

Let me just add parenthetically that the earth's varying income of solar radiation is at least partially responsible for the repetitious Pleistocene ice ages. These variations are not a result of changing solar energy output but rather are due to quasi-cyclical changes in the earth's orbital elements: the eccentricity of the orbit, the inclination of the earth's axis, and the precession of the spring point. These cycles occasionally coincide to reduce the beneficial income of radiation received by the earth and thus cause cooling. This astronomical hypothesis of ice ages has been corroborated by some geological evidence but there is still some question whether this effect alone is sufficient to account for the glaciations. The quasi-periodic recurrence of these ice ages over the past million years suggests that a repetition may occur thousands of years hence. It is comforting to think that the last ice age did not prevent the migration of people from Asia into North America and that these primitive settlers managed to survive. Thus our successors, with the help of a much advanced technology, should be able to cope with another ice age that may envelop the earth in a dim future.

There are climatic problems closer at hand to be of concern. One thing is certain: any climatic extreme observed in the past can, and probably will, recur in the future. There is enough information in the climatic archives in most of North America to make the necessary statistical analyses of various climatic elements. Such statistics will permit estimates of the probability that a given value will be exceeded. The advantage of such estimates is obvious for construction projects such as dams, roofs and towers. Similarly, precautions to meet extreme events can be taken, including planning for evacuations during floods or hurricanes. These statistical analyses are essentially predictions without date. They indicate the magnitude of climatic risks at any particular point. Regrettably, other climatic forecasts a month or season ahead are still vague and unreliable. Suffice it to state here that they are subjects of an intensive research effort but improvements are likely to be slow. An interesting sidelight of this problem is the fact that some decades in the past have shown more variability than others. Contrary to some views, in the U.S. the 1930s have been more variable than the more recent decades. This is just one reminder that there is much yet to be discovered in climatology.

There is another pesky question yet to be answered: How large is the effect of human activity on climate? On a local scale, this influence is definite and measurable. As forests are changed to fields and fields are changed to settlements, wind flow and energy balance in the lower atmospheric layers are altered. The changes in temperature, humidity and wind speed are generally small until we reach the size of cities. There the changes are very obvious, especially because of air pollution, lowered visibilities, greater fog frequency, the formation of a notorious heat island, and increases in the cloud cover and precipitation. A large contribution to the knowledge of these conditions has been made by the team at the Illinois State Water Survey in cooperation with several universities (Changnon, 1981).

The industrial effluents are now identified as the sources of acid rain, which has in recent years been such a topic of environmental concern. One can certainly measure its effect near coal-fired power plants. How far

afield the influence goes is still subject to investigation but three decades of experience in Europe make it plausible that the elements of acid deposition can travel several hundred kilometers. This problem is regional in character and is here and now.

There are some potential longer-range impacts on the atmosphere by the use of fossil fuels. The main one is the gradual increase of carbon dioxide in the air. This has been going on for a century. It has the potential of increasing the earth's temperature. By how much and how soon is highly uncertain. Estimates differ by orders of magnitude. Equally uncertain are the ultimate consequences, both locally and globally. There is widespread surveillance of these atmospheric changes. A respite of a few decades lies ahead. It is, however, imperative that this lead time be used to develop alternate energy sources in lieu of fossil fuels.

REFERENCES

Baker, D.G., 1960. Temperature trends in Minnesota. Bull. Am. Meteorol. Soc. 41: 18-27.

Blodgett, L., 1854. Climatology of the United States. J.B. Lippincott & Co., Philadelphia, 536 pp.

Brooks, C.F., 1941. Columbus and the 1498 Azores storm. Bull. Am. Meteorol. Soc. 22: 303-309.

Catchpole, A.J.W., and M.A. Faurer, 1983. Summer sea ice in Hudson Strait, 1751-1870. Climatic Change 5: 115-139.

Changnon, S.A., Jr., ed., 1981. METROMEX: A review and summary. Meteorol. Monogr. 18 (40): 181 pp.

Coues, E., ed., 1965. History of the expedition under the command of Lewis and Clark, Vol. III. Dover Publications, New York, p. 1264 (Meteorological Register).

Forry, S., 1842. Climate of the United States. S. & H.J. Langley, New York, 378 pp.

Hakluyt, R., 1589. The Relation of David Ingram. IN: The Principal Navigations, Voiages and Discoveries of the English Nations. George Bishop & Ralph Newberry, London (Reprinted - Reader Microprint Corp. 1966).

Havens, J.M., 1955. The first systematic American weather observations. Weatherwise 8: 116-117.

Kearny, M.S., and B.H. Luckman, 1983. Holocene timber line fluctuations in Jasper National Park, Alberta. Science 221: 261-263.

Ludlum, D.F., 1963. Early American Hurricanes, 1492-1970, History of American Weather, No. 1. American Meteorological Society, Boston, 198 pp.

Mason, B.J., 1976. Towards the understanding and prediction of climatic variation. Qu. J.R. Meteorol. Soc. 102: 473-499.

Mitchell, J.M., Jr., Stockton, C.W., and D.M. Meko, 1978. Evidence of a 22-year rhythm of drought in the western United States related to the Hale solar cycle since the 17th century. IN: B.M. McCormac & T.A. Seliga, eds. Solar-Terrestrial Influences on Weather and Climate. D. Reidel, Dordrecht, pp. 125-143.

Whyte, A., 1635. A Relation of Maryland, together with a map of the country the condition of plantation, his Majesties charter to Lord Baltimore translated into English. William Peasley, London, 55 pp.

ILLINOIS CLIMATE ON A GEOLOGICAL SCALE: THE LAST TEN THOUSAND YEARS

James E. King
Illinois State Museum, ENR

Climate is the primary natural factor affecting the distribution and growth of plants; it is the driving force that moves them around the landscape. This close relationship between plants and climate makes the study of climates of the past possible. Plants have only two choices when faced with a changing climatic situation: either survive or die. If they survive they do so because they could adapt to the new climatic conditions. If they die, they do so because the new conditions exceed their range of adaptability. Thus by knowing the relative abundance of plants that have lived in the past and knowing their tolerance for climatic conditions, we have a practical method of studying former climates. The plants themselves may be gone but they almost always leave a fossil record of their former presence; this provides the data with which we work.

The previous speaker, Dr. Landsberg, presented slides showing that the globe has experienced continent-wide glaciations in the not-too-distant past. In fact, for the last 2-2 1/2 million years, the Northern Hemisphere has undergone at least four and possibly more periods of glacial activity on a continental scale, separated by warm periods called interglacials such as we are currently within today. The glacial periods have generally been much longer than the interglacials. The last 2-2 1/2 million years is called the Quaternary Epoch by geologists and it emcompases the "ice ages" as well as the present.

The most obvious question is what started this current cycle of glacial activity and have these glacial periods occurred earlier in earth's history? The evidence from further back in the geological record suggests that there have been periods of continential glaciation at intervals of about 250 million years which have affected various portions of the earth's surface. The reason why these cold periods start, however, is not known and may never be known. However, it is possibly related to the movement of continental masses on the surface of the globe by continental drift, episodes of mountain building which would have drastic effects upon global atmospheric circulation, and variations in solar output.

Science, however, has a much better understanding of what is causing the present period of Quaternary glacial/interglacial cycles to occur. As Dr. Landsberg noted, the sun is the driving mechanism of our planet and slight variations in our orbit around it apparently cause variations in the amount of solar radiation the earth receives. This does not explain why Quaternary glaciation started 2-2 1/2 million years ago, but it does explain what is keeping the current cycle going. Orbital variations, slight changes in our orbit around the sun, are actually composed of three separate varations. (1) Eccentricity, which describes the change in our orbit around the sun from a circle to an oval and back every 90,000 years. (2) Obliquity or the wobble

of the earth on its axis between 21-1/2 degrees and 24-1/2 degrees from the perpendicular plane with the orbit which occurs on a 41,000-year cycle. (3) And finally a factor called Procession of the Equinoxes which is essentially the progressive movement of the position in space where the equinoxes occur. This 21,000-year cycle is caused because the exact time when the sun crosses the equator each spring and fall (called the equinox) is sightly less each year. The idea of looking at how these three separate variations relate to each other and their impact upon the amount of solar radiation the earth receives was first proposed by a mathematician named Milankovitch about 50 years ago. As with many revolutionary ideas in scinece, his hypothesis was not taken seriously at the time he proposed it. However, with the development of computers, refinement of the fossil data base and the ability to radiometrically measure a fossil's age, these orbital variations, now called Milankovitch Curves, have emerged as the potential driving mechanism behind the present series of glacial/interglacial cycles.

Climate itself leaves no direct record, no fossil evidence of past temperatures or precipitation. However, climate information is preserved in the form of the fossils of the plants and animals that have lived in the past. This form of record is called "proxy data" and it has provided science with a very detailed account of Illinois' climates for the last 20,000 years.

In addition to the record of former terrestrial biota, we can also look at evidence from the sea in the form of past sea level changes, carbonate deposition, and shifts in the species of small microscopic marine creatures that lived in the past and were affected by surface water temperature. With the exception of the evidence for sea level changes that occurs as erosion features at the ocean's edge, the studies of deep oceans are conducted on the bottom sediments recovered by long cores from specially equipped research vessels. These cores provide the best and longest of the continuous sequences of fossil data; many of them contain over a million years of sediment accumulation without any missing sections or breaks. As the small marine animals who live in the shallow zones of the oceans penetrated by sunlight die, their tiny shells settle to the bottom and slowly accumulate. By determining the shifts in the relative numbers of cold water to warm water species, a paleotemperature record for that portion of the ocean can be constructed.

In addition, because the carbonate that comprises the shells of these small creatures was derived from ocean water, it was therefore in equilibrium with the dissolved carbondate at the time the animal lived. Changes in the ratios of two common isotopes of oxygen that are associated with carbonate, O-16 and O-18, are known to vary with the amount of water locked up in polar ice. This correlates well with total global ice volumes and thus climatic conditions. On a global basis, the marine paleoclimate records are the best we have.

Paleoclimatic evidence recovered from terrestrial sources, on the other hand, is usually composed of many discontinuous shorter records, containing only the last one or two glacial cycles. With the aid of radiometric dating methods, however, these short data bases can be arranged into longer semicontinuous data sets, much like a tall cake is composed of many layers. The

majority of these records of past climate are assembled from fossil pollen data. For the geologist, pollen grains are very nice fossils with which to work. First, as any hayfever sufferer will testify, pollen is produced in incredible amounts and widely disceminated by wind across the landscape. Secondly, pollen grains are readily identifiable as to the plant that produced them, and thirdly, they fossilize extremely easily. By studying the fossil pollen grains preserved in the bottom sediments recovered from lakes, bogs, swamps, and marshes (areas of good preservation), we can very easily determine what plants were growing around the site and in what numbers, and from that data reconstruct paleovegetation and paleoclimate.

I noted earlier that North America has experienced at least four episodes of continental glaciation in the last 2-1/2 million years and there is good evidence for as many as nine glacial events in parts of Europe. This information is based on terrestrial geological evidence. On the other hand, deep sea cores from the Pacific Ocean containing the last approximately 780,000 years of data indicate that during that period there were 19 glacial/interglacial cycles! The difference in these two lines of evidence may be explained by the magnitude of the glacial event that is needed to leave evidence on land versus the ocean bottom. Current thinking is that the oceanic record is probably the most reflective of global climate. The unique feature about the deep sea record is that each glacial/interglacial cycle is almost a duplicate of those that preceded it. Each begins with a brief episode of maximum warmth followed by slowly decreasing temperatures over the next several ten's of thousands of years. Ultimately a maximum cold period is reached that persists for several thousand years and then is ended by a rapid temperature increase to the next maximum warm peak. This cycle is then repeated, over and over again. A primary feature of this ever-repeating cycle is that maximum warm conditions last only briefly, perhaps a few thousand years at most.

If we look at the relative oceanic temperatures (see Figure 1) for the last glacial cycle, we see that the previous period of maximum warmth occurred about 127,000 years ago followed by a slow decline to maximum cold (i.e., glacial) conditions about 20,000 years ago. Temperatures then warmed rapidly to the most recent maximum warm period 5,000 years ago then began cooling again. The important fact here is that the duration of maximum warm conditions does not appear to last for long. Presently we are already beginning to cool toward the next future glacial cycle. This climatic cycle has been repeating itself for the last 2-1/2 million years and we have no evidence to indicate that it will not go on doing so into the future.

The oecanic record is global in scope and thus general in nature. If we want to know more about the specific paleoclimates of Illinois and how they have affected the environment, we must look at the terrestrial record based on fossil pollen grains from Illinois and the adjacent Midwest.

Before we discuss the fossil pollen data from Illinois, it would be best if we reviewed the modern vegetation of the region first. Between the Rocky Mountains and the east coast of the United States the vegetation changes from dry short grass plains to moist deciduous forest reflecting the west to east increase in the amount of annual precipitation. In the center of this

region, Illinois contained, at the time of Euro-American settlement, a mixture of forest and prairie. Prairie dominated on the level uplands in the central portion of the state while forest predominated along the rivers and in the rugged southern section. A particularly intriguing question for students of midwestern vegetation and ecology has always been, when did the prairies first become established and what was the exact sequence of vegetation and climate change that preceded it?

To answer these questions and learn more about how the modern vegetation of Illinois developed out of the glacial environments of the Ice Age, I studied a series of sediment cores form bogs and marshes down the length of the state. From this work, I want to discuss the fossil pollen data from one small bog in central Illinois named Chatsworth Bog in Livingston County near the little town of Chatsworth, because they illustrate nicely the vegetation and climate history of Illinois. Chatsworth bog is a glacial kettle located in an area that was last glaciated about 18,000 years ago. A kettle is a geological feature that results from the burying of a large block of ice under a mass of glacial debris; as the ice block melts a depression is formed in which a small lake develops. With time, the kettle fills in with the peaty debris of the plants that lived around it and slope wash from the surrounding hills. This natural in-filling proceeds slowly year by year and as it does it incorporates the pollen of the neighboring vegetation into the deposit. Chatsworth Bog today is completely filled with these naturally accumulated sediments and thus contains a continuous record of the regional vegetation. A sediment core revealed 13 meters of accumulated deposit and radiocarbon dating indicated we had the past 14,000 years of data. From this core we removed small samples of sediment every 20 centimeters for processing for fossil pollen.

From each sample we identified and tabulated at least 300 pollen grains to have a statistically reliable data base for interpretation. The pollen data are presented in a diagram of the percentages of pollen from each species plotted against depth in the core (see Figure 2). In this manner the variations through time of each type of plant are highlighted. The radiocarbon ages of levels within the core are also shown. For clarity the diagram is divided into pollen assemblage zones based on the changing pollen percentages of the different plants. The pollen at the base of the core is clearly dominated by that of spruce. Radiocarbon dating reveals that stratum is 14,380 years old. Just above this point spruce declines and is replaced by ash. The abundance of other plants is changing at this time as well; oak begins to increase and so does elm. The level at which these changes occur is the border between pollen assemblage Zones I and II. These changes in the vegetation reflect the climatic warming that was occurring at the end of the last glaciation. About 11,280 years ago, ash--after reaching quite high percentages--declined and was replaced by elm and oak as the dominant types of pollen being deposited into Chatsworth Bog. The climate was continuing to get warmer and dryer. By the end of Zone III, the climate was so warm and dry that oak was the only major tree in central Illinois. All of the trees that required more moisture had disappeared.

Also at this time, 8,300 radiocarbon years ago, there was an extremely important change in other pollen groups. Although the percentages of tree pollen do not change much, there are increases in the pollen of the important grasses and herbaceous plants. At 8,300 years ago, these prairie indicators increase in percentage and remain prominent to the present. These small increases in grassland species signal the beginning of the formation of the midwestern prairies. Oak continues to be the dominant tree but it is now restricted in its distribution; the state had become a grassland.

The beginning of the prairies, 8,300 years ago at Chatsworth Bog, marks the peak in the warming trend that ended the last glaciation. This peak shows clearly on the plot of the oxygen isotope variations from the Pacific Ocean. Pollen data from Illinois and elsewhere in the midcontinent indicates that this peak of maximum warm lasted for only several thousand years before cooling began. It has been cooling slowly ever since.

Pollen data are just that, raw data that must be interpreted and analyzed before vegetation patterns and climate changes can be inferred. A complicating factor in developing climatic information from pollen data is that plants do not respond independently to temperature and precipitation. A plant responds primarily to moisture stress, a combination of the two environmental parameters. For any given amount of soil moisture, stress will be less with cooler temperatures. Thus it is often convenient to think of a single factor such as "effective moisture" as controlling plant growth and distribution.

Figure 3 shows the changes in vegetation in Illinois during the last 18,000 years based on pollen data from throughout the region and my interpretations of the climatic conditions. The vegetation stages are arranged geographically north to south and plotted against time. The lower portion of the figure is what I call a "conditions curve"; it is an integration of both temperature and precipitation much as a plant might experience effective moisture. The axis of this curve (the line through the center) approximates modern conditions. There is no vertical scale on this graph, but the area above the modern line is warmer/dryer than the present and the area below it is cooler/wetter than the present. The further the curve extends from the axis, the more extreme the conditions.

From 18,000 to about 13,000 years ago, there was ice in northern Illinois and a mixture of tundra plants and scattered spruce trees in the south. The "conditions curve" shows the climate much colder than the present. Starting about 13,000 years ago, throughout much of the state the ice and tundra began retreating to the north and a forest dominated by coniferous trees developed. As the climate continued to warm, cold temperature deciduous trees began to replace the conifers. By 11,000 to 10,000 years ago, the coniferous trees gave way to more warm temperate deciduous trees. About 9,000 years ago, the climate had warmed sufficiently so that all of the cool temperate trees had been replaced by those that could now tolerate the warm/dry climatic conditions. Shortly after this, the climate became even warmer and dryer than the present and the prairies became established.

The oceanic temperature record indicates that prairie formation occurred during the warmest and dryest climatic episode the Northern Hemisphere has experienced since the last climate peak 127,000 years ago. Both data sets, marine and terrestrial, indicate the climatic peak lasted only about 3,000 years! By 5,000 years ago, cooling had started once again and this is reflected in the return of oak forest along the borders of the prairies in northern Illinois and the expansion of small forested areas called prairie groves within the prairie.

The cooling, however, has not been a straight slow decline, but rather like a roller-coaster, sometimes dipping down, sometimes climbing up but always in a downward direction. As such, there have been periods within the last few thousand years that have been cooler or hotter than the present. About 600 to 700 years ago, a cool period began that was to last for about 400 years. This time, known historically as the Little Ice Age, was a period when mountain glaciers world-wide advanced far down slope and many villages in the high Alps were overridden and buried by ice. There were widespread crop failures in northern Europe both from the cool/wet climate as well as killing frosts in summer months. There are no historic records for this cool period in Illinois but the fossil pollen data tell us that spruce, pine and birch trees increased in number throughout the Great Lakes region. These changes were not of sufficient magnitude to affect central Illinois; it remained prairie.

About 200 years ago, coinciding with the Euro-American settlement of the Midwest, the climate once again warmed slightily to our present conditions and these were exceeded briefly at least once in this century during the droughts of the 1930s.

This review of climate on the geological scale is broad but it illustrates the one point I want to leave with you: that climate is dynamic. It has changed greatly in the past 2 million years in what appears to be a long-term repeatable pattern and we can clearly see its effects on the vegetation of Illinois during the last 20,000 years. Climate will probably continue to change in the future. Unless altered by human interference, a new unknown factor and the subject of this conference, the data suggest that the climate will continue to cool toward a new episode of continental glaciation.

ILLINOIS CLIMATE FOR THE PAST 100 YEARS

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INTRODUCTION

Climate must be viewed, like water and land, as a major natural resource of Illinois. Climate is not static and is always varying over time scales ranging from a few years, to decades and to centuries. Further, much of North America in the past 100 years has experienced a relatively warm period, when compared with temperatures experienced over the past several hundred years. Proper assessment of the current climate, including existing trends, changes in weather variability and alterations in weather extremes, is integral to the water, energy, agricultural and transportation issues. When and how these four resource and activity areas (agriculture, energy, water and transportation) reach critical stages in Illinois is considerably affected by our climate conditions (Changnon, 1981).

Agricultural technologies have become very sophisticated over the past 40 years to increase production. We depend on specialized field equipment and grain drying facilities; we have requirements for specific dry or wet periods to apply and get a successful reaction of fertilizers, herbicides and pesticides; and we possess a variety of plant types that can be chosen to optimize production in any one of a variety of growing seasons (dry, wet, hot, short season, etc.). In other words, we have finely tuned agricultural technologies. In some ways, the new technologies have reduced certain of the weather problems that used to limit production, but at the same time they have made us more vulnerable to weather, especially to achieve high production to meet production costs. Knowledge of future weather events and awareness of climate trends, as best we can develop them, can and must be utilized to help optimize food production in Illinois.

In a similar vein, the rapid and all-encompassing use of air conditioning coupled with long-recognized needs for structural heating have made Illinois a major energy consumer, particularly during the two extreme seasons, winter and summer. The great expansion in the use of air conditioning, coupled with our demands for home and industrial heating, makes the rate and amount of utilization of energy in Illinois very critical to supplies and suppliers. The frequency of extremely cold or hot periods (weeks, months or seasons) in winter or in summer is now a critical issue in meeting energy demands (Changnon et al., 1980).

Water, as the third climate-impacted area, is intimately linked to the aforementioned agriculture and energy issues since both are great consumers of water. Climate effects on Illinois' water resources are most easily visualized by the dramatic impacts of floods and droughts. A change to more of these, or to more severe extremes of wet and dry conditions, would be of singular consequence to the state's economy and its institutions. In a more gradual and complex way, available water resources are being impacted by ever poorer water quality. Soil erosion is a major unresolved problem aided or

abetted by changes in high rainfall rates and high winds. Management of water pollution including that resulting from industrial wastes, sewage and disposal of hazardous wastes is not resolved and is also related to the climate conditions. The water supply for northeastern Illinois, for example, is adequate to 2000 only if the deep tunnel and reservoir systems are completed to allow for local water treatment and flood control. Major potential future users of water in Illinois are apt to be irrigation and synfuel plants. Their water demands, and the availability of water for them, are directly linked to the climate.

Transportation networks in Illinois are complex, interrelated and vital to the state's commerce. Most parts of this vital system are vulnerable to certain climate conditions. The massive surface highway network which serves the movement of automobiles, intercity transport, trucking, and commuter movement in urban centers, is vulnerable to weather, which delays or deters both construction and traffic in winter storms and which subjects highways to more destruction by severe winters and frequent freeze-thaw cycles. More adverse weather in any season limits commercial air traffic at Chicago, the world's busiest airport. The severity of winter conditions ices up our rivers and Lake Michigan, either stopping or reducing freight movement.

The race to keep pace with these problems and to seek their solutions requires consideration of the near-term climatic conditions and knowledge of shifts and trends that are occurring. These trends to colder and wetter conditions are not always reflected in the average weather values of the past 30 to 40 years. In these four major issue areas, our systrems are functioning but often in economically or environmentally vulnerable positions. Our energy, transportation, agricultural and water systems are essentially designed, or are operated, in relation to many factors including the climate. The climate values used are based on data from discrete historical periods. These systems are vulnerable to climate conditions of today and the future. For instance, a 32 percent reduction in corn yields occurred in Illinois in 1974 and more than 50 percent in 1983, and both were weather-related.

An added example is another aspect of the recent climate shift and its impacts. Since Illinois became a major user of air conditioning in the last 20 years, Illinois has experienced only one year, 1983, with long runs of high ($\geq$ 100°F) daily temperatures such as those experienced in the 1910s, 1930s and early 1950s. July 1980 was the first hot July since 1955 (26 years and with only three days of $\geq$ 100°F) and serious power shortages occurred with curtailment of air conditioning. One question becomes, "Can we meet these extreme hot periods if they come again, and how often may they occur? Or, what can be said to suggest their occurrence and severity in the next 20 years?" The hot summer of 1983 with up to 19 days with temperatures over 100°F raised these questions again.

Dealing with Climate Factors

The great influence of weather and its summation over time, that is, the climate, on Illinois is clear (Changnon, 1981b). Wise decisions involving use of climatic data and information require awareness of the fluctuations in climate since climate is not stable.

The focus of this paper is on trends and fluctuations found in the entire period of record, but generally those since 1890. A more extensive report is available (Changnon, 1983). Inspection of current trends, frequency of extremes and the variability of weather conditions offer guidance as to the type of climate Illinois may experience in the future. We know that the best "normal" for estimating next year's average precipitation and temperature values is that based on the average of the past five years (Lamb and Changnon, 1983).

PRECIPITATION CHANGES

Data from all available stations were used to determine in each year a statewide "average" precipitation value for 1840 to 1980. The values from the 1840-1890 period, when many fewer stations existed, are less representative of the true statewide value than the values since the turn of the century. Nevertheless, the statewide annual average values were used in Figure 1.

Two general features are indicated in the 140-year history of the state's precipitation. First is the erratic nature of precipitation with occasional very high and low 5-year values. There is a tendency for peaks about every 15 to 25 years. Note the highs in 1845, 1880, 1905, 1925, 1945 and 1970. The other feature of the distribution is the tendency for lower values in the 1910-1940 period, with higher values in the earlier years of the 19th century and higher values in the more recent years (1960 to 1980). The three highest 5-year values in the 140-year period occur at the beginning (1840-1845) and in the most recent 15 years (1965-1979).

A network of 89 stations existing from 1916 through 1980 was used to compute the frequency of days when 2 or more inches of rain occurred in a 1-day period in Illinois. If one or more stations had a $\geq$ 2-inch amount in a given calendar day, it was counted as an event. The frequency of such events is presented in Figure 2. The overall trend from 1916-1980 is upwards with the highest values in the last few years, in agreement with the heavier statewide precipitation value shown in Figure 1.

Figure 3 is based on the extent of areas that received 3 or fewer inches of rainfall in July-August of each year since 1931. Three inches of rainfall is approximately 50 percent of the average. There was a greater frequency of extensive dry areas in the 1930s and 1950s, and the 1960s and 1970s had very small areas of deficient summer rainfall.

The temporal frequency of droughts in Illinois, based on precipitation deficiencies for periods of varying duration, is shown in Figure 4. The number for each drought indicates its rank, based on statewide severity, with rank 1 the worst drought. Droughts of all durations were relatively frequent in Illinois from 1909 through 1941, then after about 10 years with little drought activity, there were severe droughts in the early 1950s. Since then, Illinois has been relatively drought-free except for the short-duration, low-ranked droughts in the late 1970s.

FIGURE 1. Illinois average annual precipitation, based on 5-year periods.

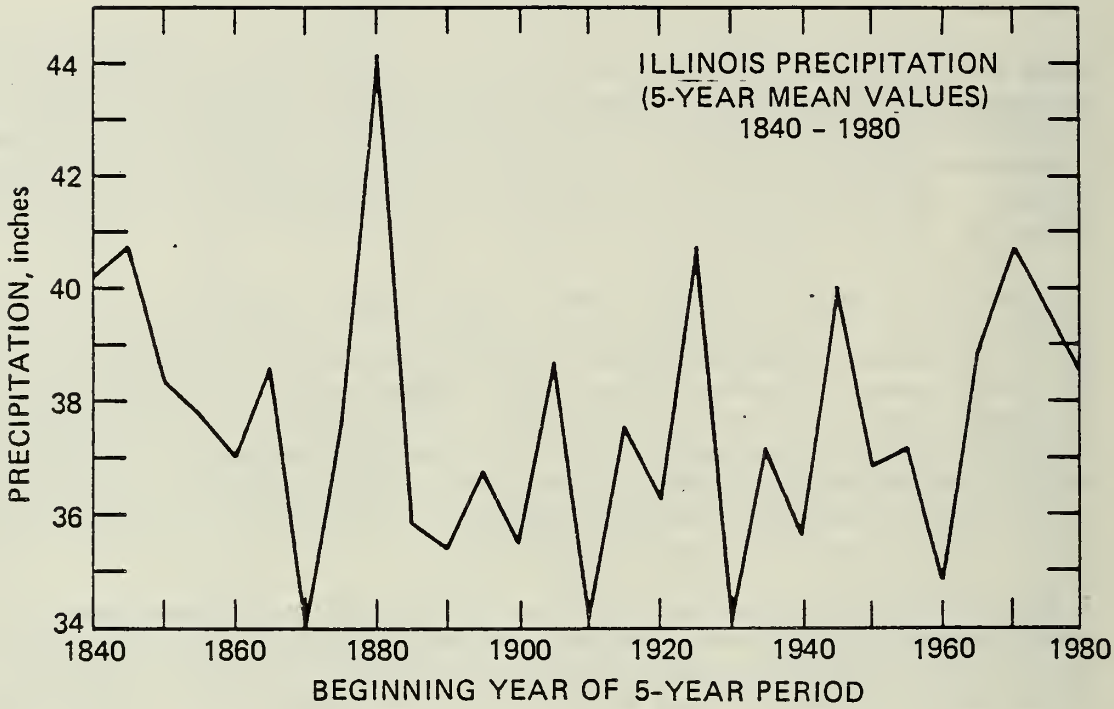


FIGURE 2. Illinois frequency of 1-day rains of 2 inches or more, per decade, 1911-1980.

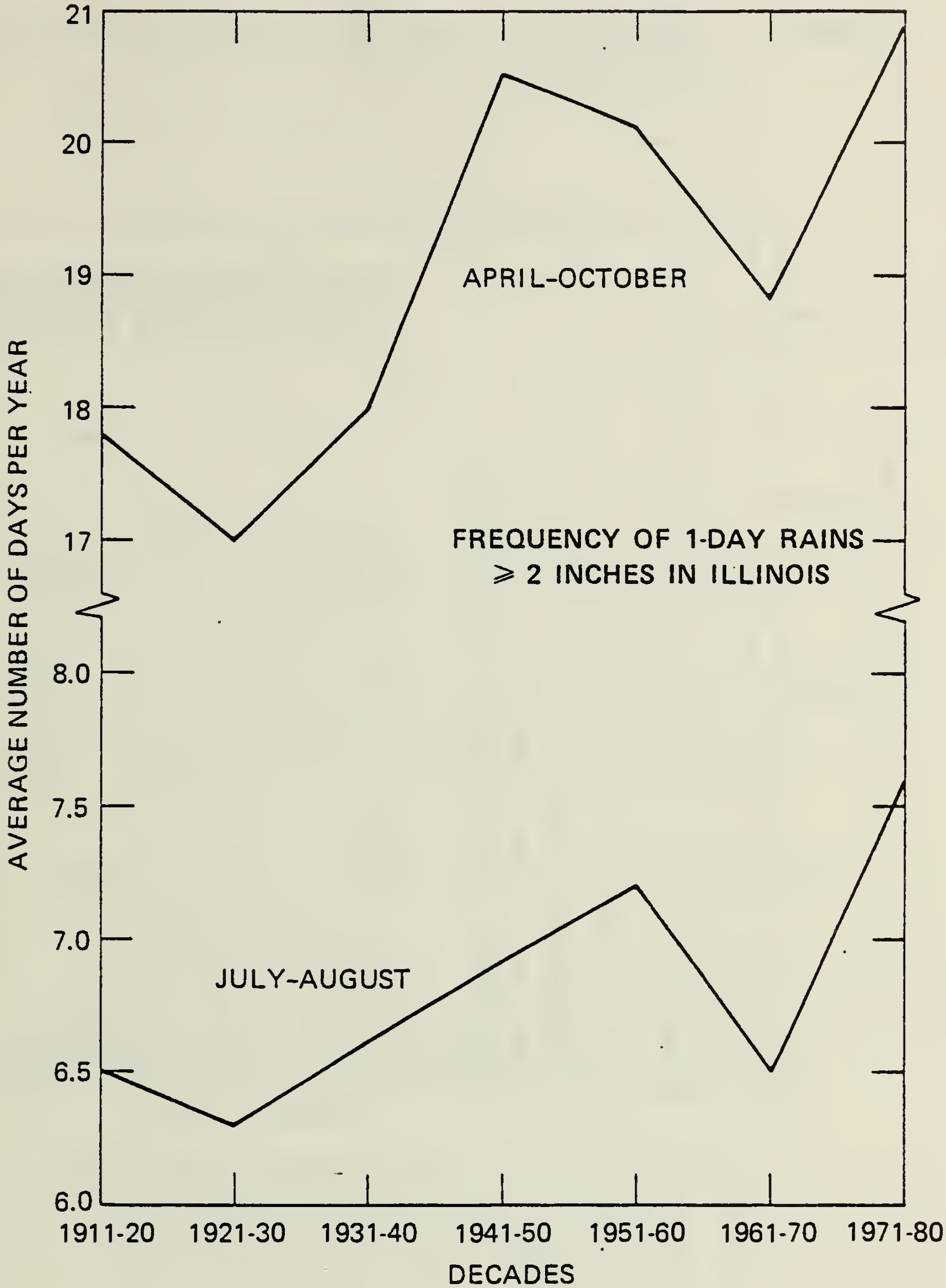


FIGURE 3. Areas receiving 3 inches or less rainfall during July-August of each year, 1931-1982, in Illinois.

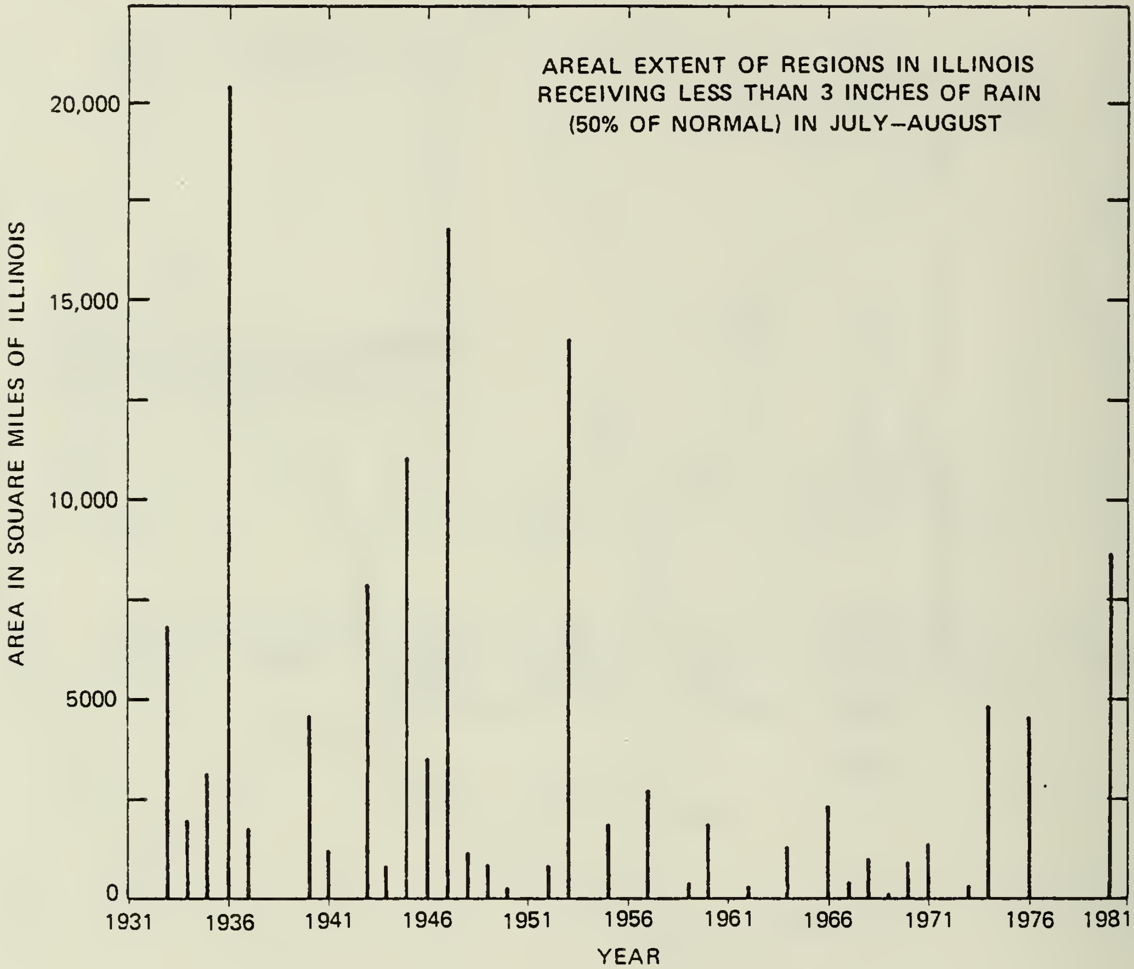
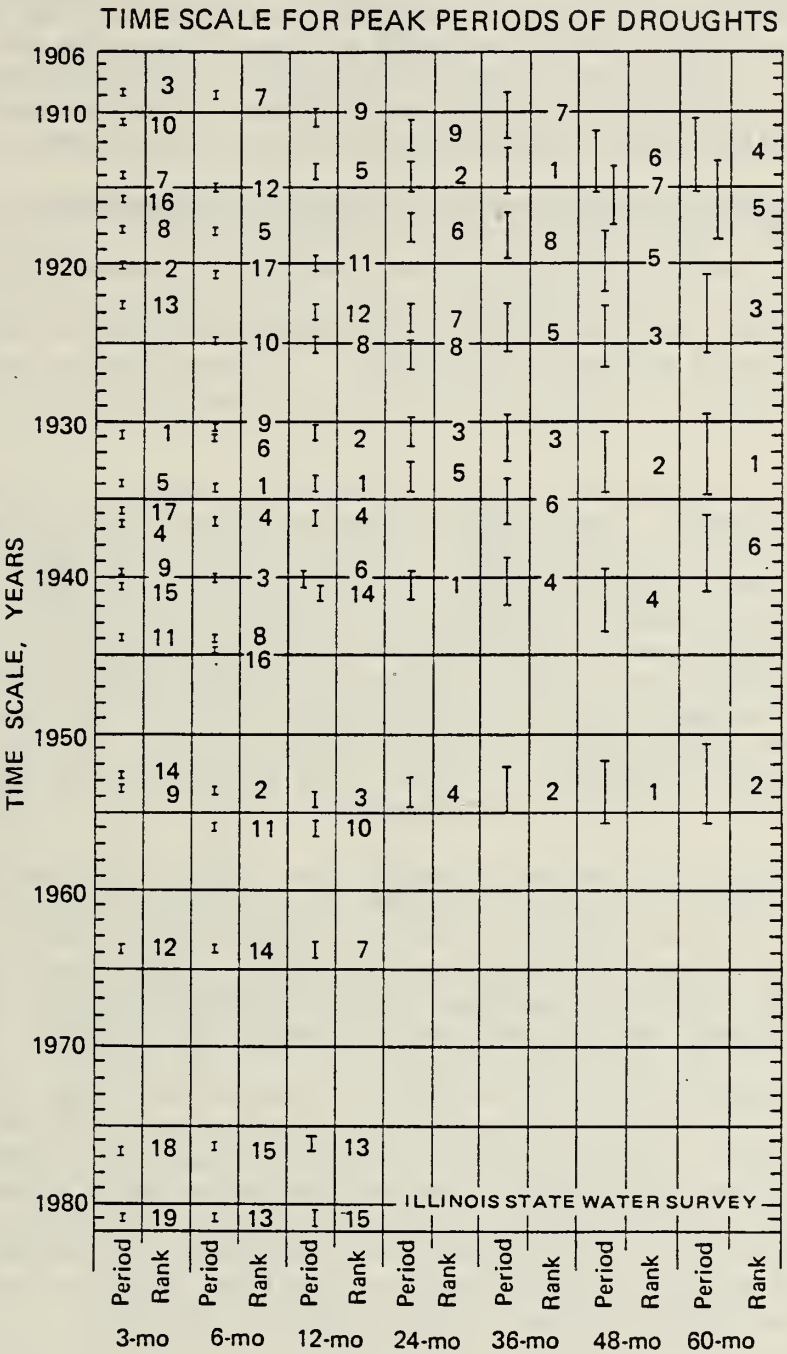


FIGURE 4. Occurrence of droughts in Illinois during 1906-1982 based on drought of varying length ranging from 3 to 60 months.



Another expression of precipitation relates to severe winter storms, defined as storms that produce either 6 inches of snow or widespread glaze over 5,000 square miles or more per storm. The 5-year frequencies appear in Figure 5. The 5-year mean is 28 storms, and in the earlier part of the century, 1901 to 1940, only two 5-year periods exceeded the mean, and storm frequencies were generally low. Beginning in 1941, the frequency increased considerably with high values achieved in 1971-1975 and 1976-1980. The increase has been sizable as Illinois has shifted to both a wetter and colder climatic regime.

Figure 6 presents decadal average precipitation values for spring, summer and fall, based on three subdivisions of Illinois, and for Illinois as a whole. The April-May curves (Figure 6a) show a general increase from 1895 to 1974, then a decrease. The July-August curves reflect early and late peaks with minimums in the 1925-1944 period. The September-October values show a peak in 1925-1934 and a minimum in 1955-1964. All three seasons exhibit uptrends and/or high values in one or both of the last two periods (1965-1974, 1975-1982).

Data from six stations were used to examine the temporal frequency of days of $\geq$ 0.01 inch rainfall. The 5-year values are summarized in Figures 7a and 7b. For example, the 1901-1905 period at Chicago had 620 days (an average of 124 per year) of measurable rain days. The stations in the northern half of Illinois show relatively uniform distributions during the 1901-1945 period, followed by a decrease during 1946-1965, and then an abrupt increase in measurable rain days to century high peaks in 1971-1975. These curves do not show a major decrease in rain days during the droughts of the '30s. The curves for the three stations in the southern half of Illinois are generally similar to those in northern Illinois. The measurable rain day frequencies support the trend to wetter conditions during the last 15 years.

The 5-year totals for seasonal snowfall (See Figure 8) reveal the Aurora values were higher during the 1951-1980 period than in the prior 50 years. The Urbana data show a decline from 1901 through 1925, then a flat distribution with an increase beginning in 1951-1955 (like Aurora), reaching the peak values of the 80-year period during the last 20 years. The Mt. Vernon and Anna (southern) curves show very similar distributions.

Figure 9a presents the 5-year values for freezing rain days in northern Illinois. Low and relatively unchanging frequencies exist from 1901 through 1940. Thereafter, the frequencies increased dramatically through 1950, remained relatively stationary, and then increased again at Peoria and Chicago during the 1971-1980 period, reaching their 80-year peaks. The data for the southern half of the state (See Figure 9b) have similar temporal distributions with maximum increases during 1946-1955, then values become fixed, and then sharp increases during the last 15 years.

The 80 values of precipitation in May-August of each year at Urbana were used to determine the 25 wettest May-August periods, and the 25 driest. The number of these in each decade appears in Table 1. This shows a peak of wet seasons in the 1970s (6 out of 10 possible), with no dry seasons in this

FIGURE 5. The statewide frequency of severe winter storms per 5-year periods.

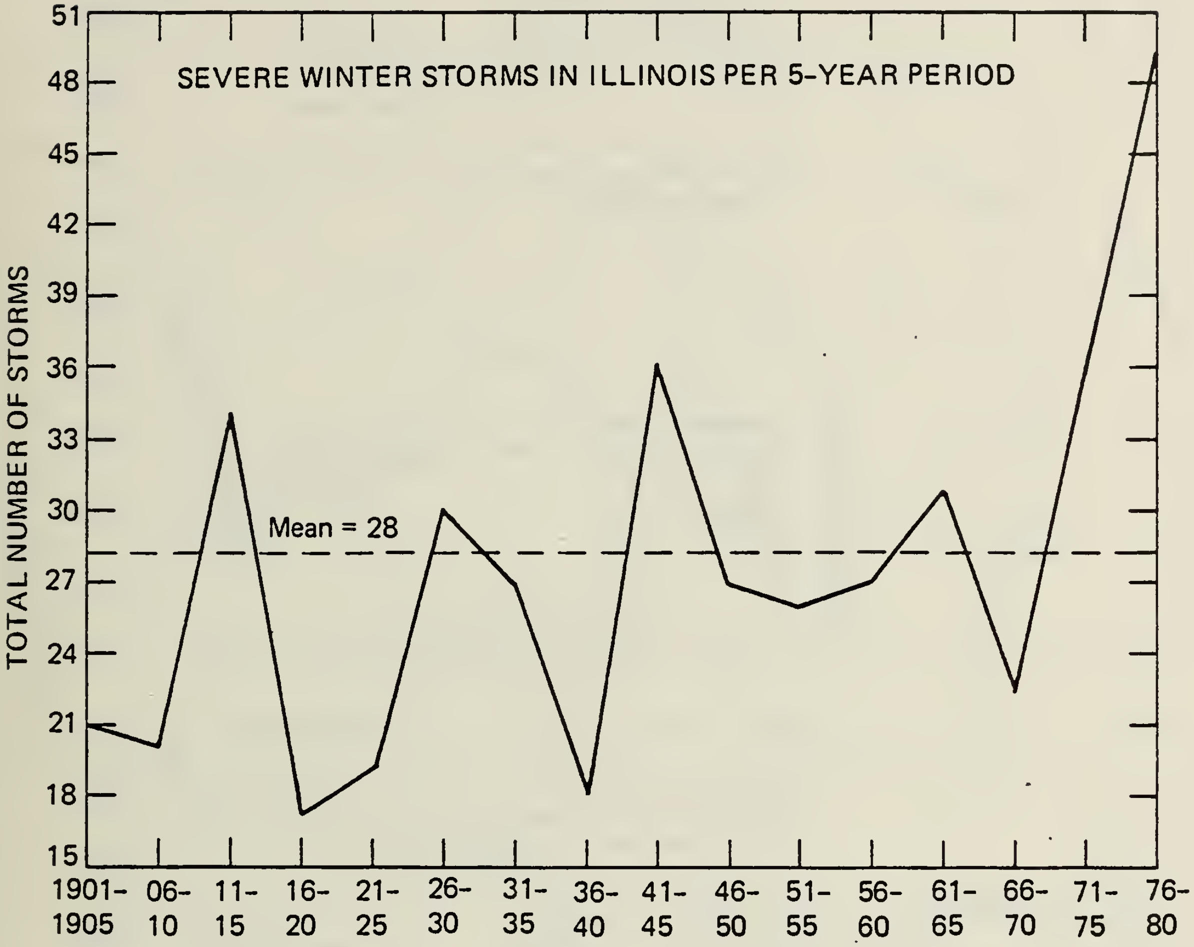


FIGURE 6. Seasonal average precipitation values for decades for 3 areas of Illinois and the entire State.

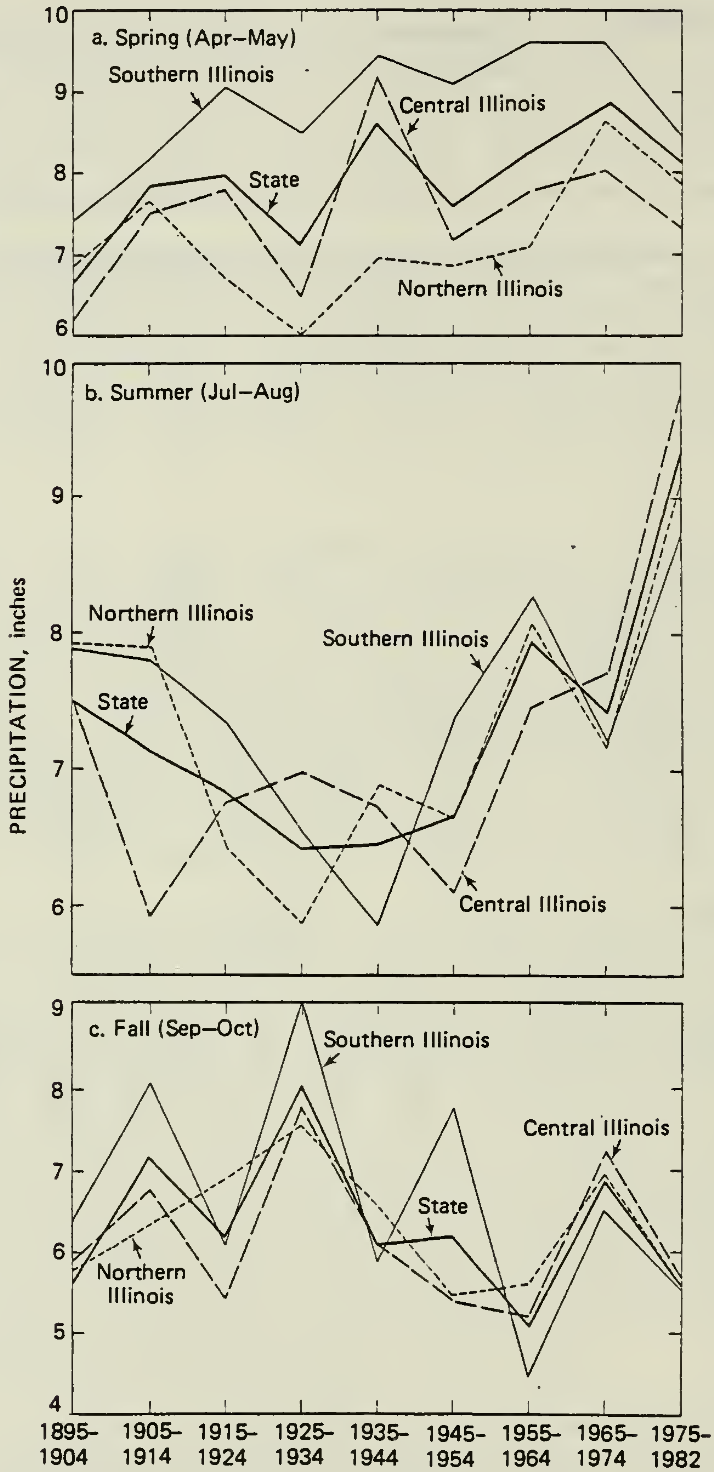


FIGURE 7. Frequency of days with ⩾ 0.01 inch of rain per 5-year period.

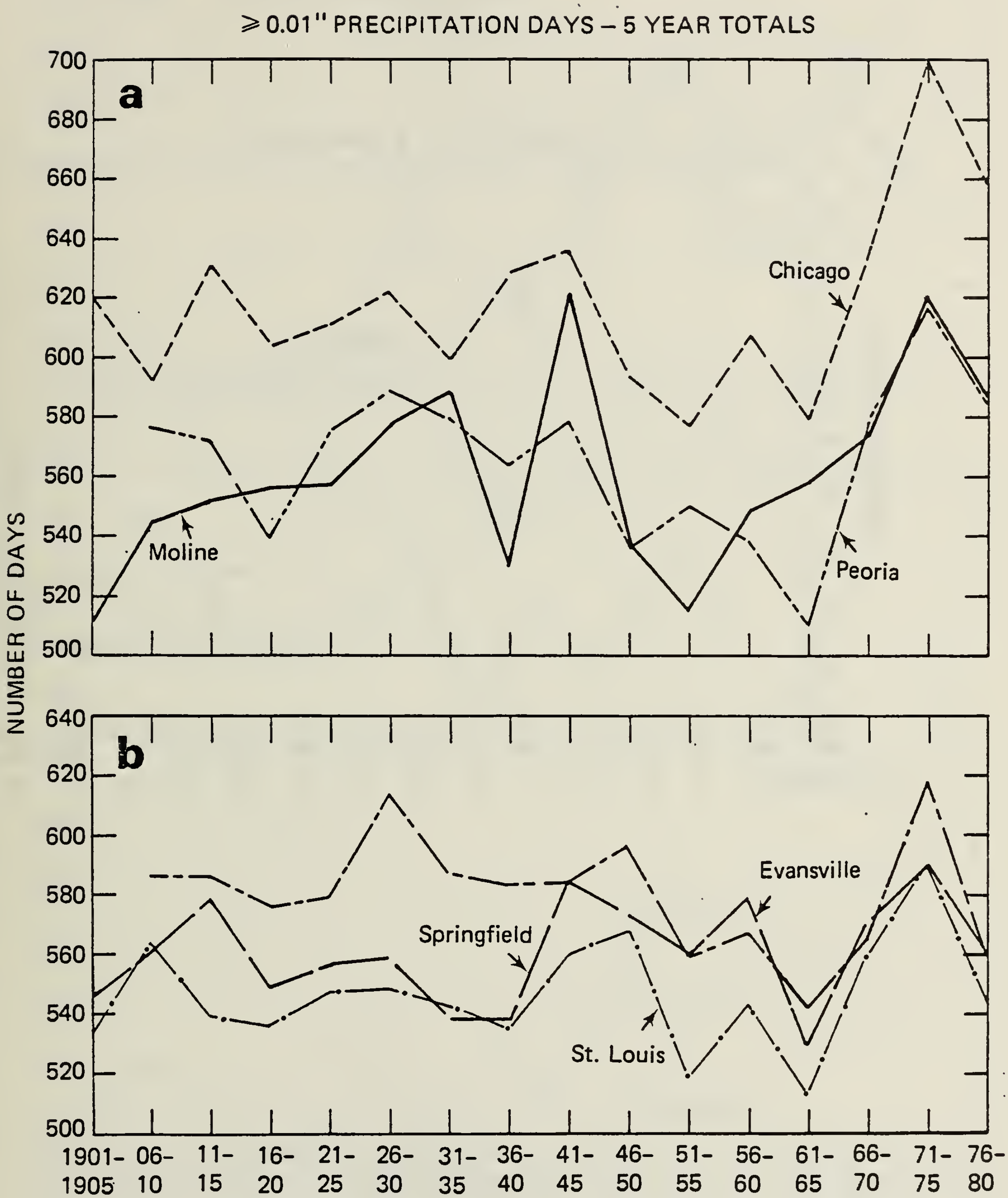


FIGURE 8. Snowfall average values for 5-year periods.

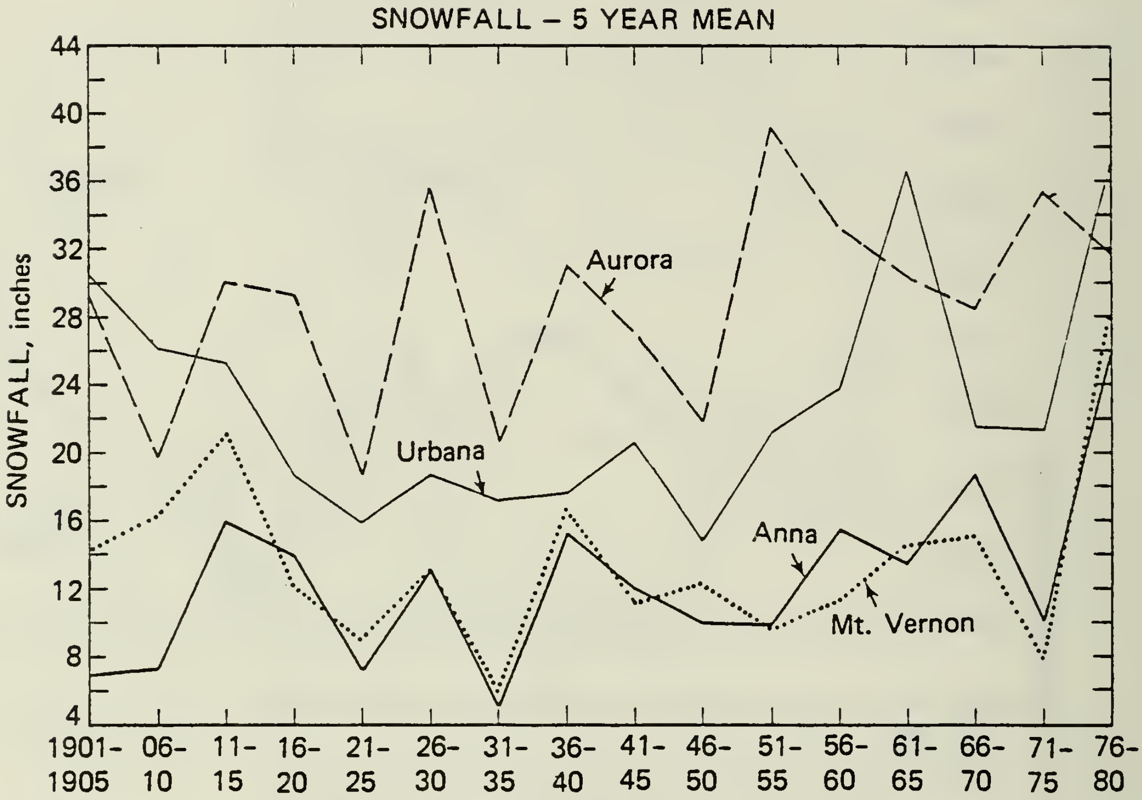
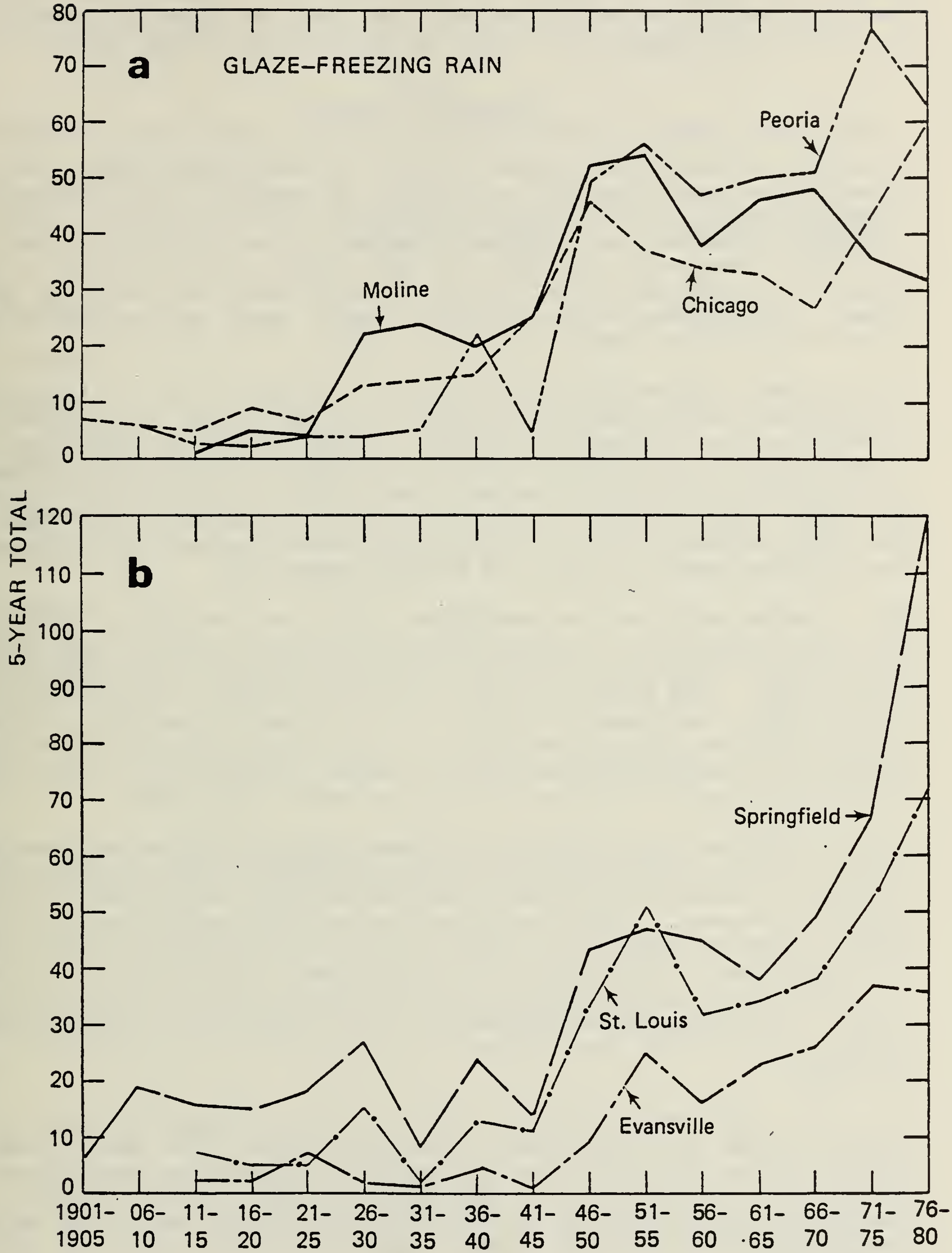


FIGURE 9. Frequency of days with glaze for 5-year periods.



decade. The 1940s was another period of generally wet summers and relatively few (only one) dry May-August periods. The 1960s was a period of extremes with three of the wettest May-August periods and six of the driest.

TEMPERATURE CHANGES

Temperature trends can be created by their surrounding environment. For example, towns and cities with a population of more than a few thousand have measurable "heat islands." Thus, the temperature data collected in 1900 in a community with a few thousand persons but which grows to 100,000 by 1980 would show a temperature increase that was related to the influences of the urban area growing around the station. Thus, it would not sample the natural change in the temperature over Illinois. Hence, great care was made in the selection of station temperature data to study.

Temperatures have been measured in Illinois routinely and on a daily basis from somewhat before 1840 to the present. Many of the earlier, pre-1860 observations were not based on the daily maximum and minimum temperatures (they often lacked thermometers for this purpose), but were based on temperatures measured at three or four set times during the day such as 6 AM, noon and 6 PM. These were then combined to obtain daily and monthly averages. This method probably produced a slightly different statewide annual temperature than one based on maximum and minimum temperatures.

The statewide annual average temperature values were combined to form 5-year means (See Figure 10). Two major features are shown in the 140-year history of the state's temperatures. First is the general upward trend from 1840 through 1935. This 95-year period of warming caused the statewide temperatures to rise from around 50°F to 54.5°F. The lowest 5-year value occurred in 1855-1859 when the value was 49°F. The second major feature of the distribution is the cooling trend that has lasted since 1935. The 5-year value for 1975-1979 was 51.3°F, down 3°F from the peak in 1930-1934.

The stations used to display seasonal temperature differences were selected largely to form a north-south axis since temperatures in most seasons show a latitudinal variation across the state, the variation being greater in the winter than summer. The winter season (December-February) values for 1905 to 1982 are shown in Figures 11a and 11b. The maximum temperatures show a peak in 1925-1934 and in 1945-1954, with a general decline after 1954. All stations show their lowest maximums in the 1975-1982 period. Most stations show a peak in the winter minimum temperatures (See Figure 11b) in the 1945-1954 period, except for the two southern Illinois stations which peak in 1925-1934.

The spring (April-May) seasonal maximum and minimum temperatures (See Figures 12a and 12b) show temporal distributions that differ greatly from those of winter. Basically, the maximum spring temperatures show a general uptrend with a peak achieved in 1955-1964. The lowest decadal maximum temperatures occurred either in 1905-1914 or 1915-1924. The minimum spring temperatures (See Figure 12b) showed a general uptrend as well, also peaking in 1955-1964.

TABLE 1. Number of Wet and Dry May-August Periods at Urbana, 1901-1980.

	Wettest 25 Years	Driest 25 Years
1901-10	3	2
1911-20	3	6
1921-30	3	3
1931-40	1	5
1941-50	5	1
1951-60	1	2
1961-70	3	6
1971-80	6	0

FIGURE 10. Illinois mean annual temperatures, based on 5-year periods.

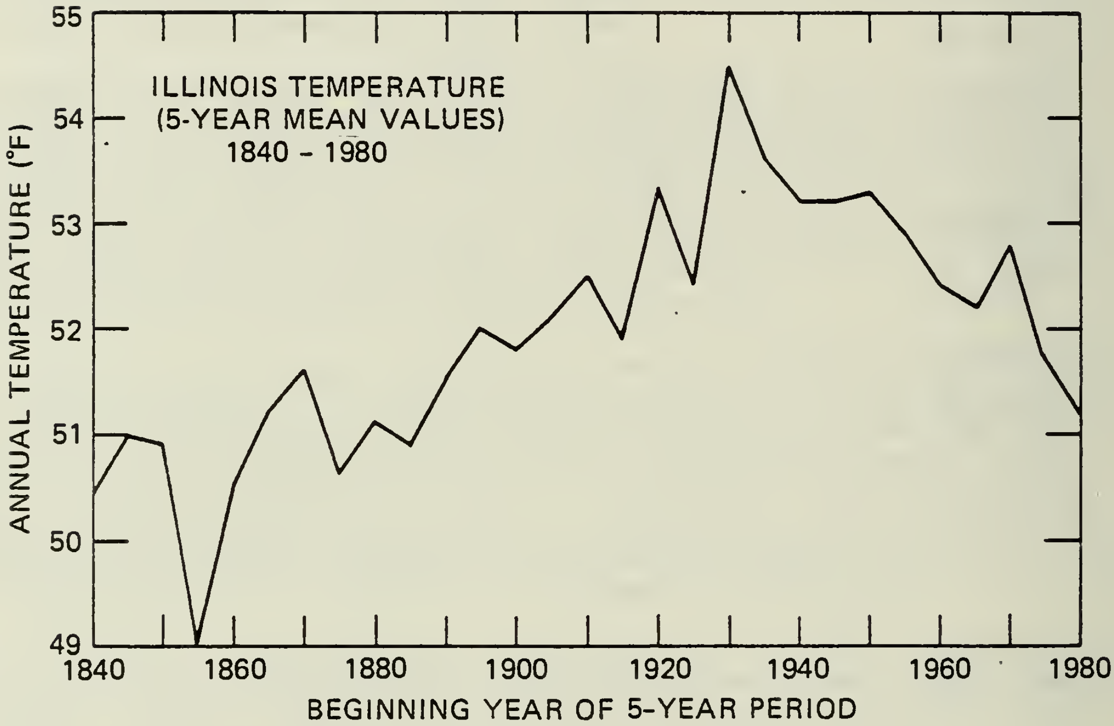


FIGURE 11. Winter season mean temperatures per decade.

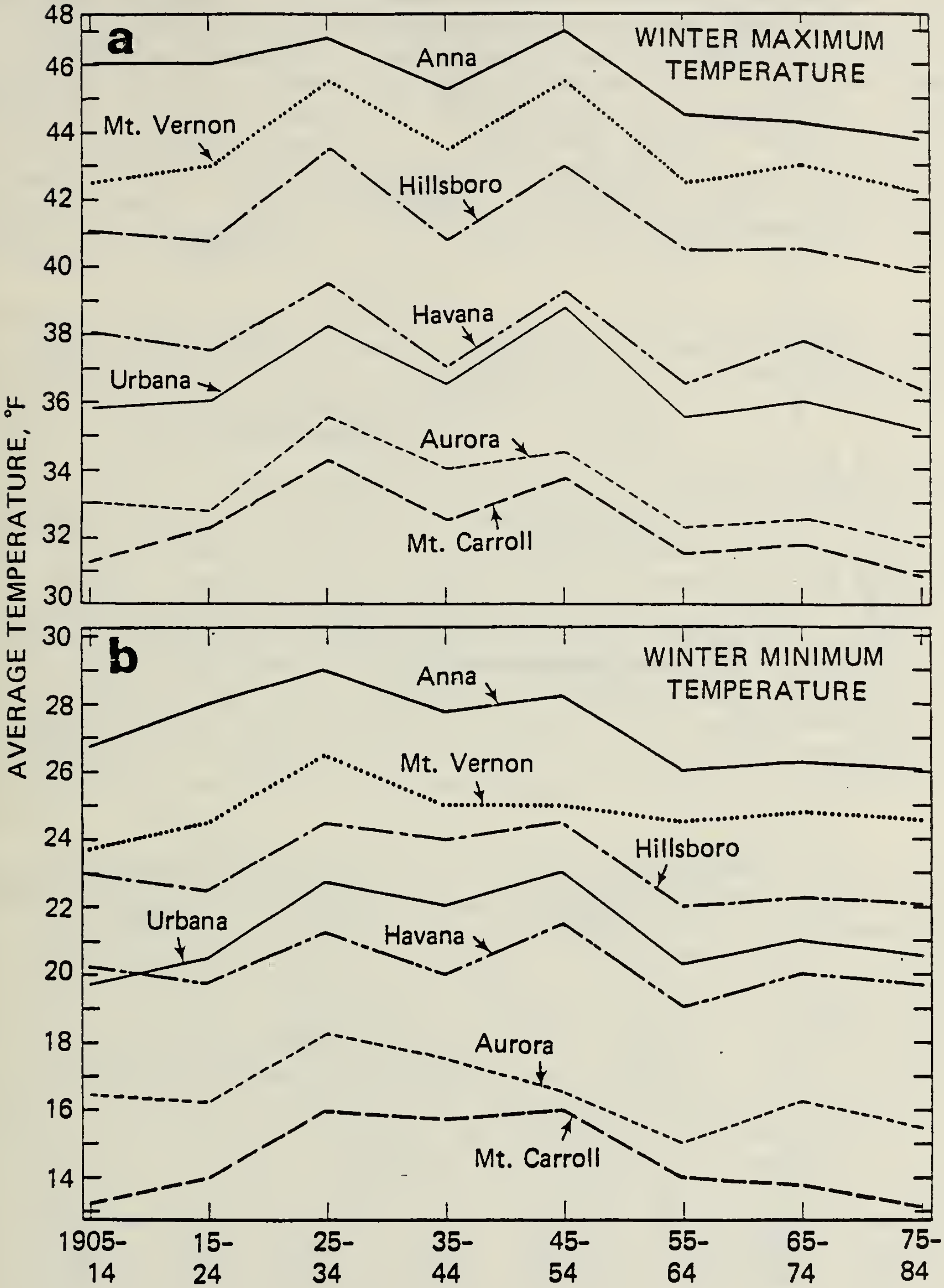
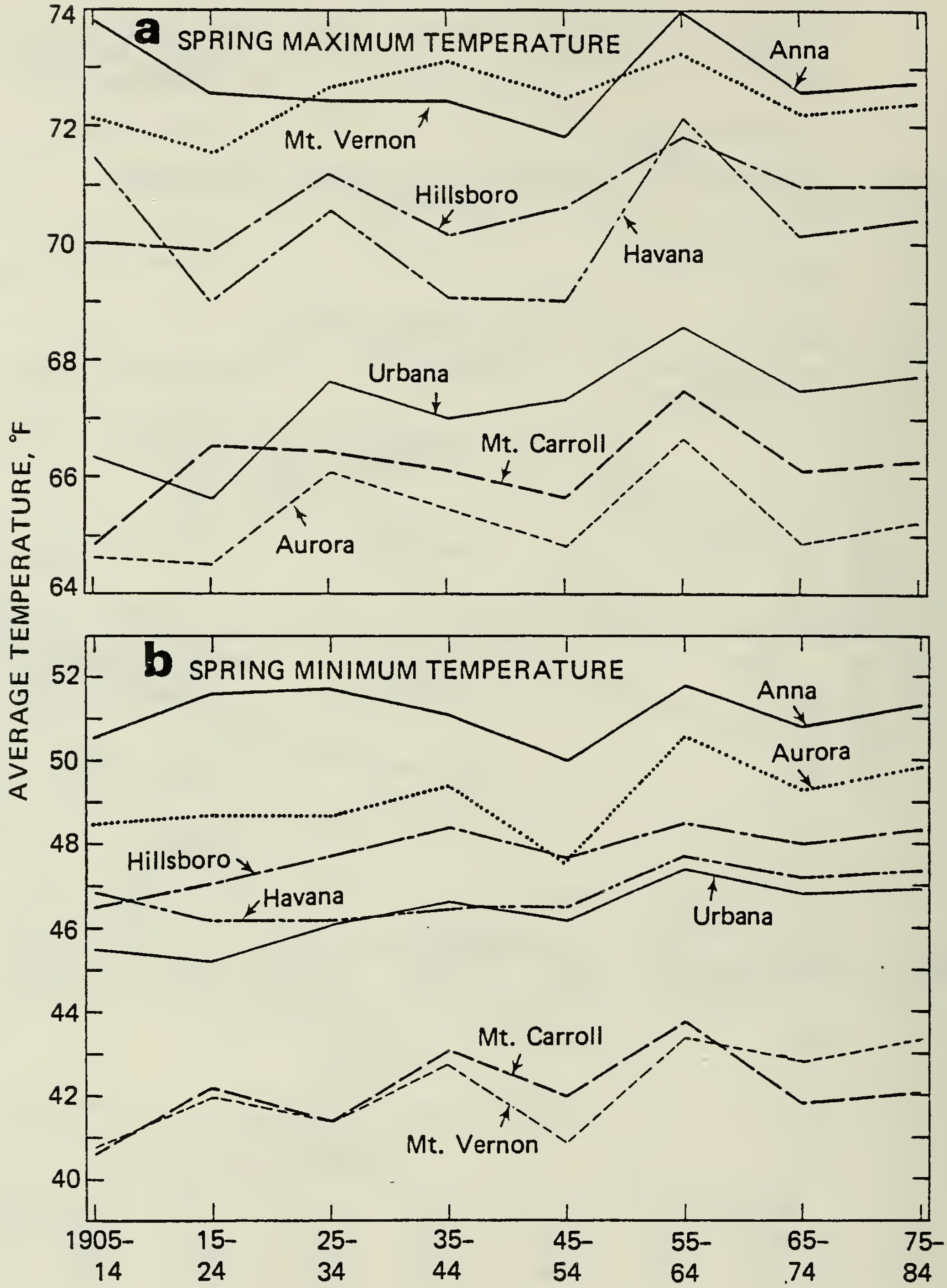


FIGURE 12. Spring season mean temperatures per decade.



The temperature values for the summer season (July-August) are shown in Figures 13a and 13b. The average maximum summer temperatures show a relatively flat distribution from 1895 to 1934 with a peak in 1935-1944, followed by a sharp decline thereafter. The statewide warm period of the 1930s (in Figure 10) was largely determined by the peaking of both winter and summer temperatures during that decade, as shown in Figures 11 and 13, but was less reflected in the spring temperatures. The lowest decadal values for the summer maximum temperatures are found during 1975-1982 except at Mt. Carroll which has its lowest value in 1955-1964. The summer minimum temperatures (See Figure 13b) reveal general trends upward from 1895 through 1944, and then a slight down trend.

Data from nine substations scattered throughout the state were used to measure length of the growing season, defined as the period between the last spring temperature of 32°F (or lower) and the first fall temperature of 32°F (or lower). The stations chosen represented relatively stable stations and/or those in very small communities.

The annual values of growing season were used to calculate decadal averages, and these are plotted in Figure 14. Inspection suggests that most stations show some form of temporal increase, particularly during the most recent two decades. However, the values for Jacksonville and Monmouth show different temporal distributions with peaks (greater lengths) in earlier decades. The recent uptrend (increase in days) at Aurora could relate partially to the growth of the urban community. The record at New Burnside is in a very small community and should not be so affected. In general, it could be concluded that a moderate recent increase in the length of the growing season is largely a function of changes in the last date of spring freeze which has become 6 to 10 days earlier and reflects the spring warming trend (See Figure 12).

The long-term means of the maximum and minimum temperatures, based on a 1901-1970 period, were used to calculate the departures of the maximum and minimum temperatures in each month. In most months when the maximum temperature is above the mean, the monthly minimum is above it also, or vice versa. A month with "moderated" temperature conditions is unusual. It is defined as one that had a) its average maximum temperature below the long-term mean, and b) minimum monthly temperature (same month) above the long-term mean. In other words, the maximum and minimum temperatures were closer together than usual. The number at each station per decade is shown in Figure 15. For example, at Aurora the number in the 1901-1910 decade was 12 out of 120 possible months (10 years x 12 months). The temporal distribution of these months suggests an increase with time, reaching decadal maximums at Aurora, Urbana and Mt. Vernon during the last two decades. However, New Burnside in extreme southern Illinois does not show a comparable increase. Changnon (1981a) has shown that these increases in months with moderated temperatures were caused by additional cloudiness which are partially a result of cloudiness produced by contrails from jet aircraft activity.

FIGURE 13. Summer season mean temperatures per decade.

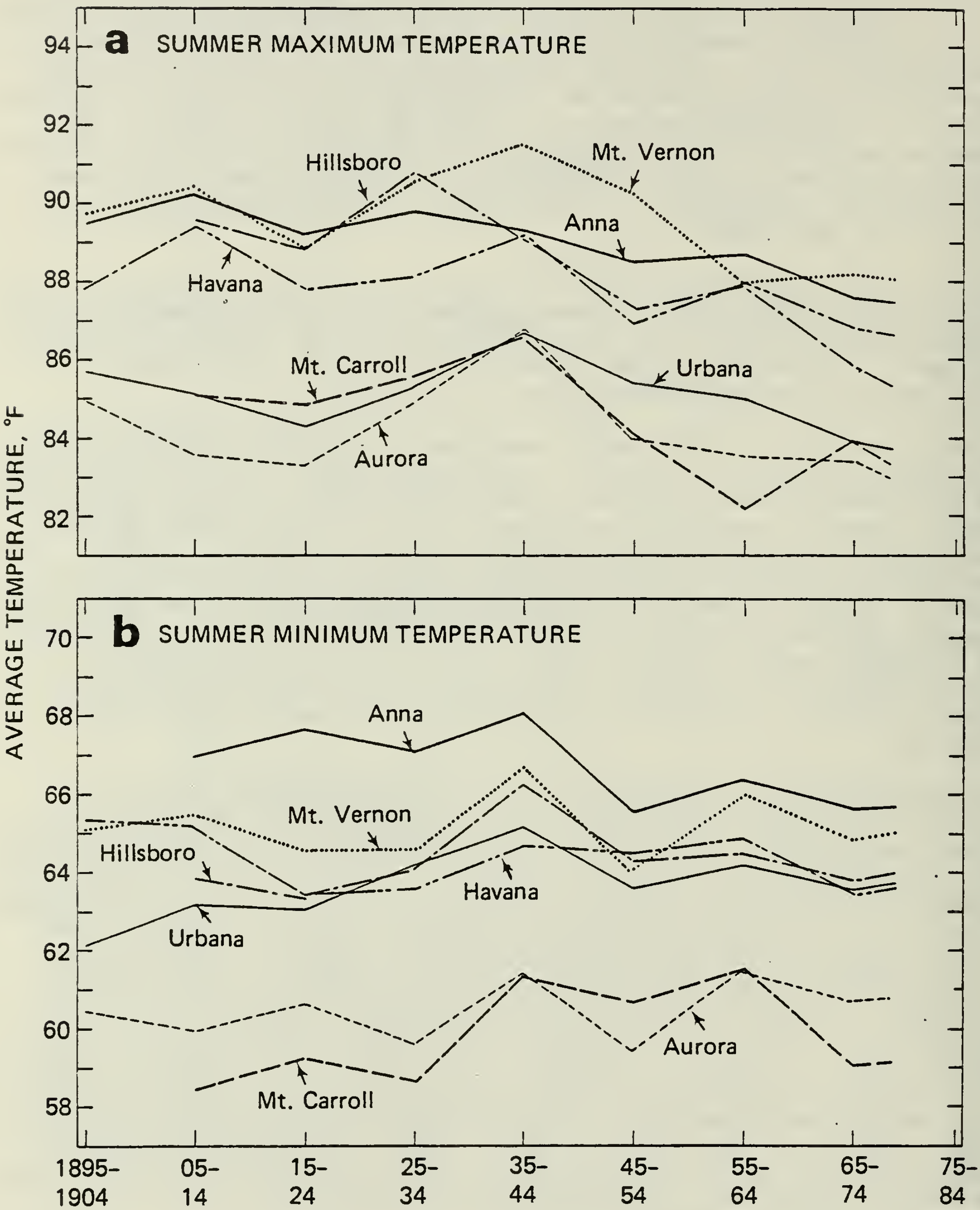


FIGURE 14. Average length (days) of growing season per decade.

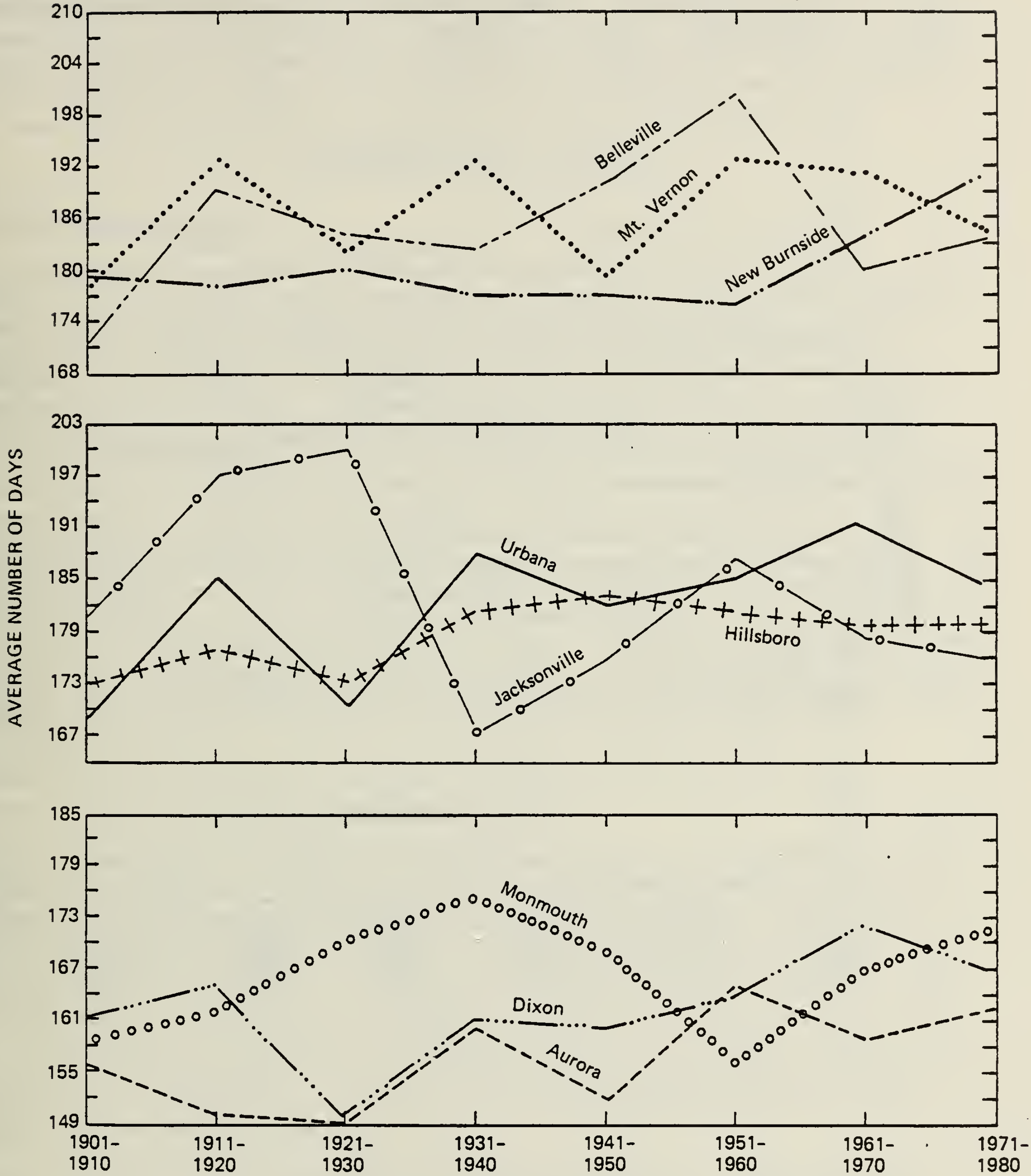


FIGURE 15. Number of months per decade with moderated temperatures.

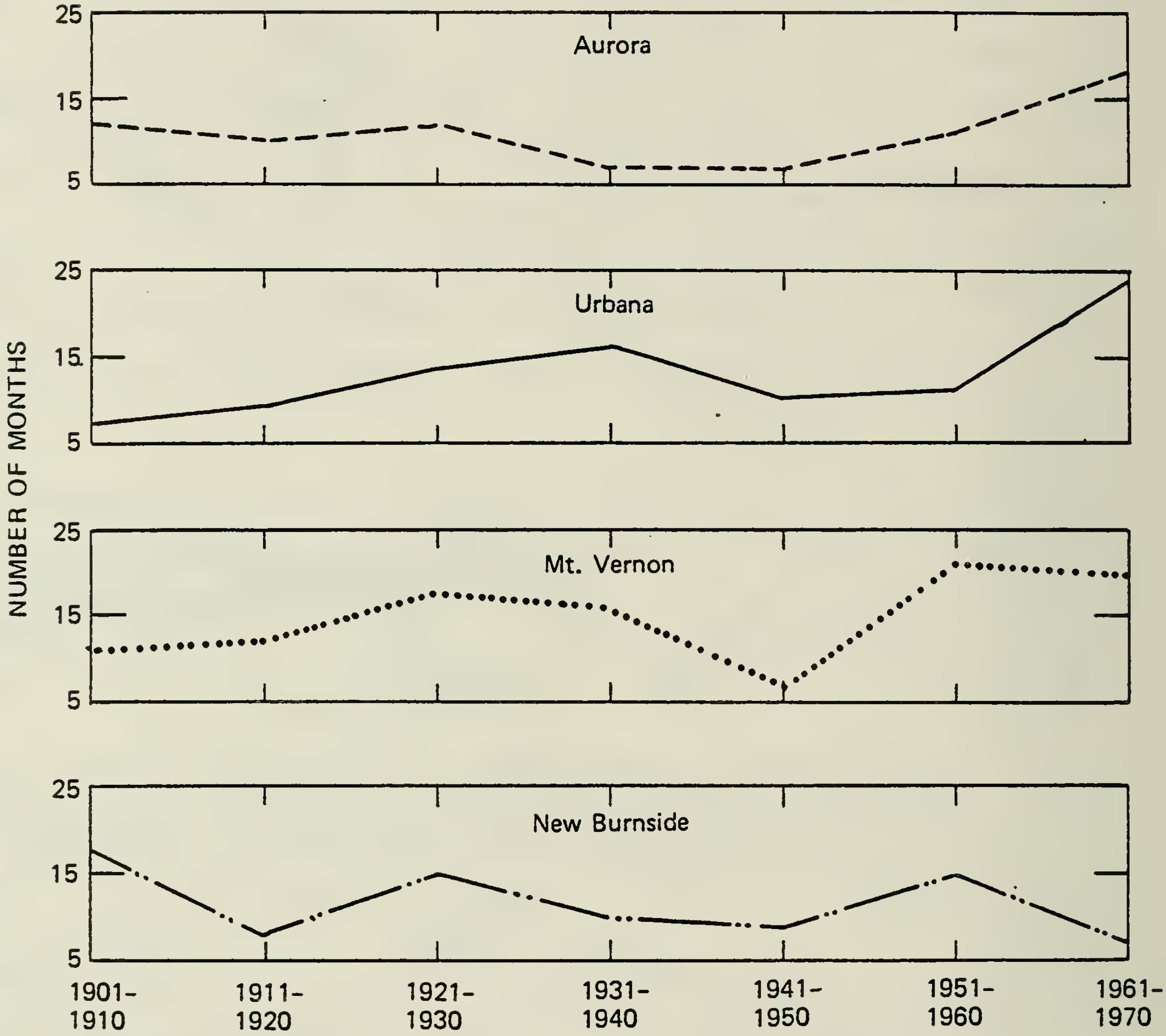


Figure 16 is based on 10-year moving averages of the July average temperatures for Peoria for 1856-1980 (Vinzani, 1982). The July value showed major oscillations with peaks in the 1880s and 1930s. A recent decrease in July temperatures is seen but has not exceeded the lows in 1905 and in the 1860s. Figure 17 shows the 10-year moving averages of temperatures from 1856 up to 1935, followed by a rather rapid decline to the all-time low in the 1970s.

CHANGES IN OTHER CONDITIONS

Sky Cover and Sunshine

The single most important factor controlling the climate of Illinois is the amount of solar energy being received throughout the world. Unfortunately, there are no long-term records of solar radiation in Illinois that allow study of the long-term temporal fluctuations. However, long records are available for two important atmospheric conditions related to radiation: cloud cover and sunshine. These data were examined for historical fluctuations and trends. Figures 18 and 18b present annual totals for 5-year periods of the number of cloudy days (0.7 or more cloud cover for the day). The curves of the six stations are typified by continuous increases over the 80-year period. However, the increase in cloudy days from 1901 through 1950 at most stations was a more rapid increase than the increase since 1950. Several stations showed a secondary major increase beginning with 1966. The latter increase has a possible relationship to jet-aircraft induced contrails (Changnon, 1981a). At all stations, the lowest decadal value of cloudy days was 1901-1910, and the highest was 1971-1980. This shift is matched in the loss of clear days, not in partly cloudy days. In general, the sunshine data support the findings from the cloud cover; that is, there has been a general decrease in percent of sunshine, particularly in the northern half of Illinois.

Visibility and Related Air Quality Conditions

Temporal changes in visibility and other conditions which affect visibility (smoke, haze and dust) were examined. Visibility measurements at the six first-order stations were available from 1951 through 1980. The January average visibility values for 5-year period are shown in Figures 19 and 19b. The stations show varying trends. Visibility generally improved over the 30-year period at Peoria and Chicago (increasing at Chicago from 7.5 miles in 1951-1955 to 8.9 miles in 1976-1980). The Moline and Evansville values do not show distinct upward or downward trends in visibility, whereas the St. Louis and Springfield visibility data for January suggest a decrease in visibility. Visibilities in July at all stations except Chicago show a decrease from 1951 through 1980.

The frequency of days when smoke or haze was observed in the atmosphere is shown in Figures 20 and 20b. Except for St. Louis, all stations show relatively low values from 1901 through 1930. Thereafter, and depending on locale, sharp increases are shown at all the northern Illinois stations. Sudden increases occurred at Springfield and St. Louis in the 1941-1945

FIGURE 16. July average temperatures at Peoria.

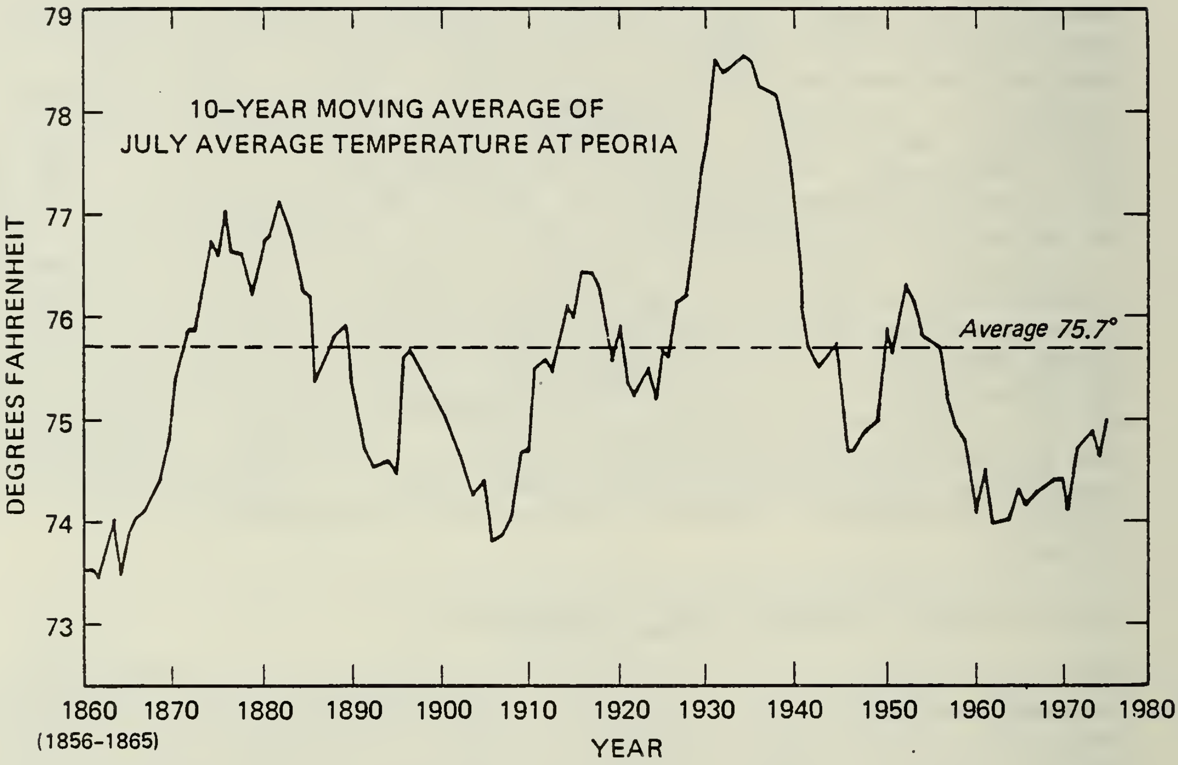


FIGURE 17. January average temperatures at Peoria.

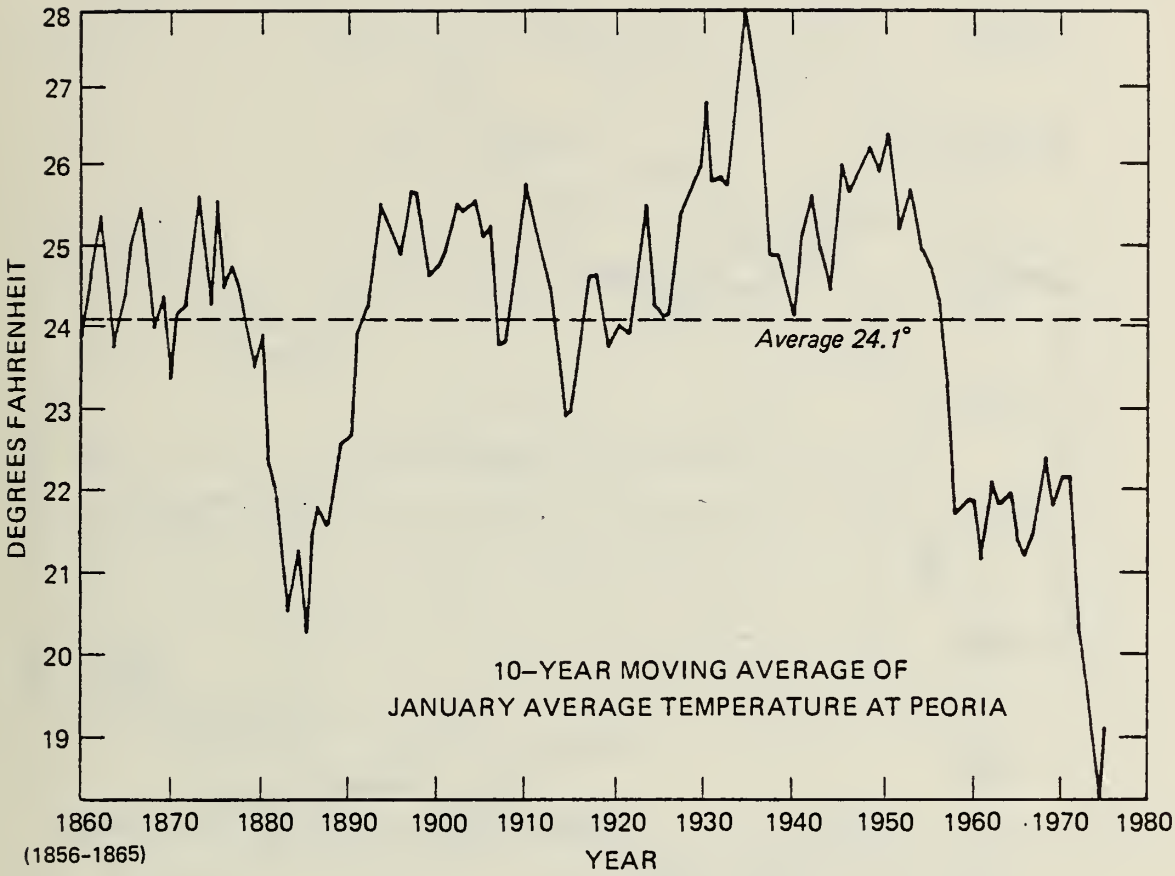


FIGURE 18. Frequency of cloudy days from 1901 to 1980.

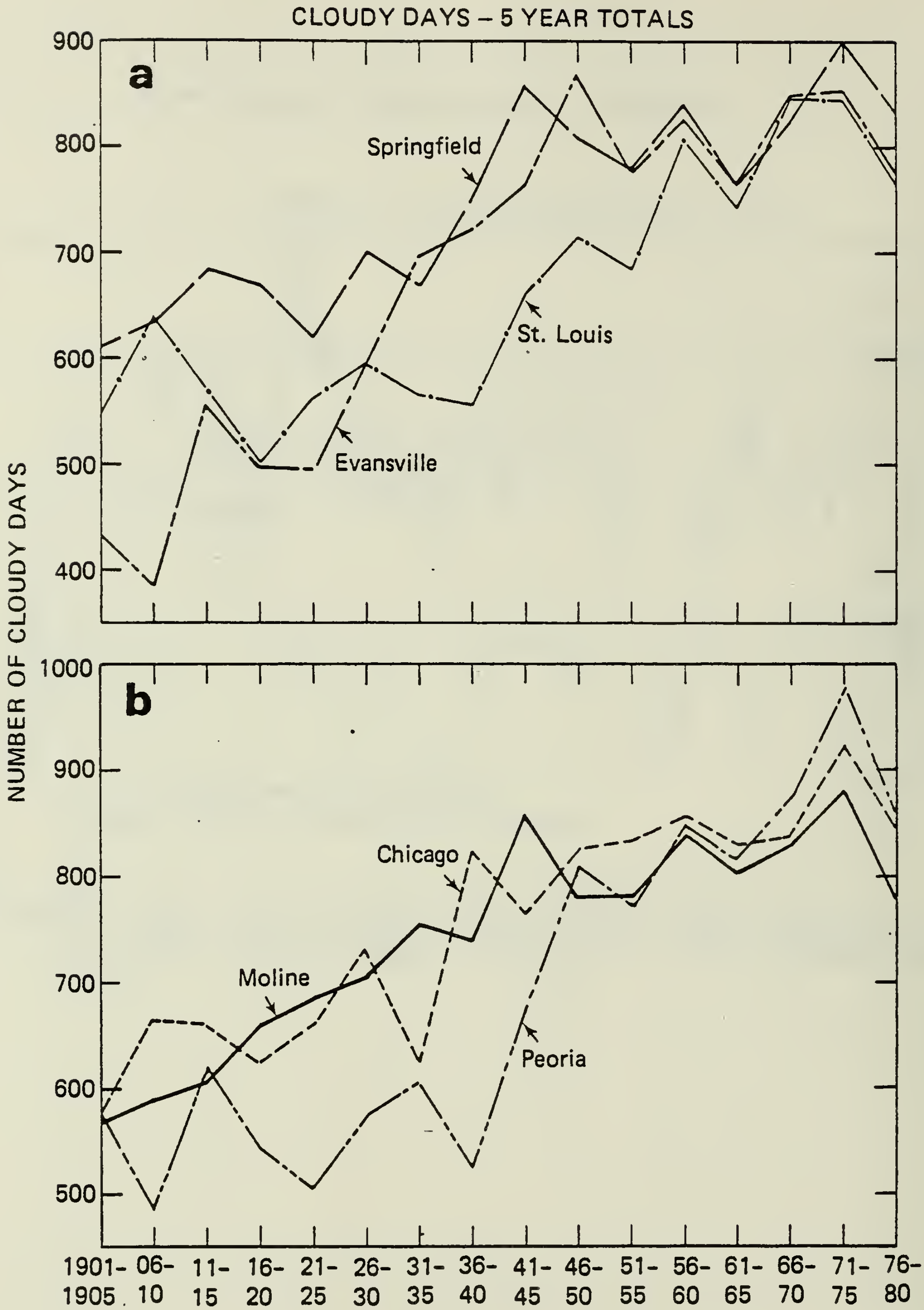


FIGURE 19. Average visibility in January based on 5-year periods.

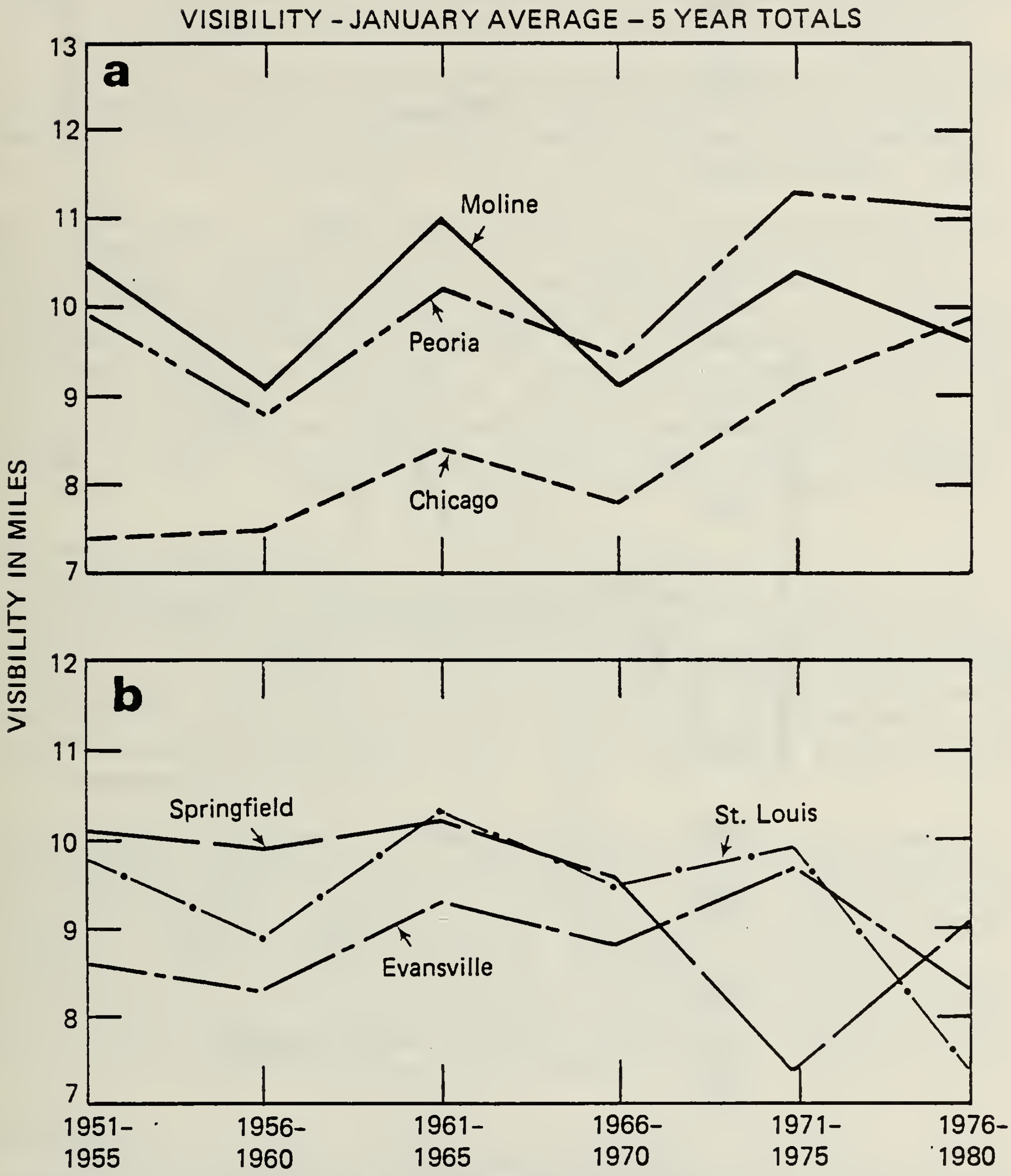
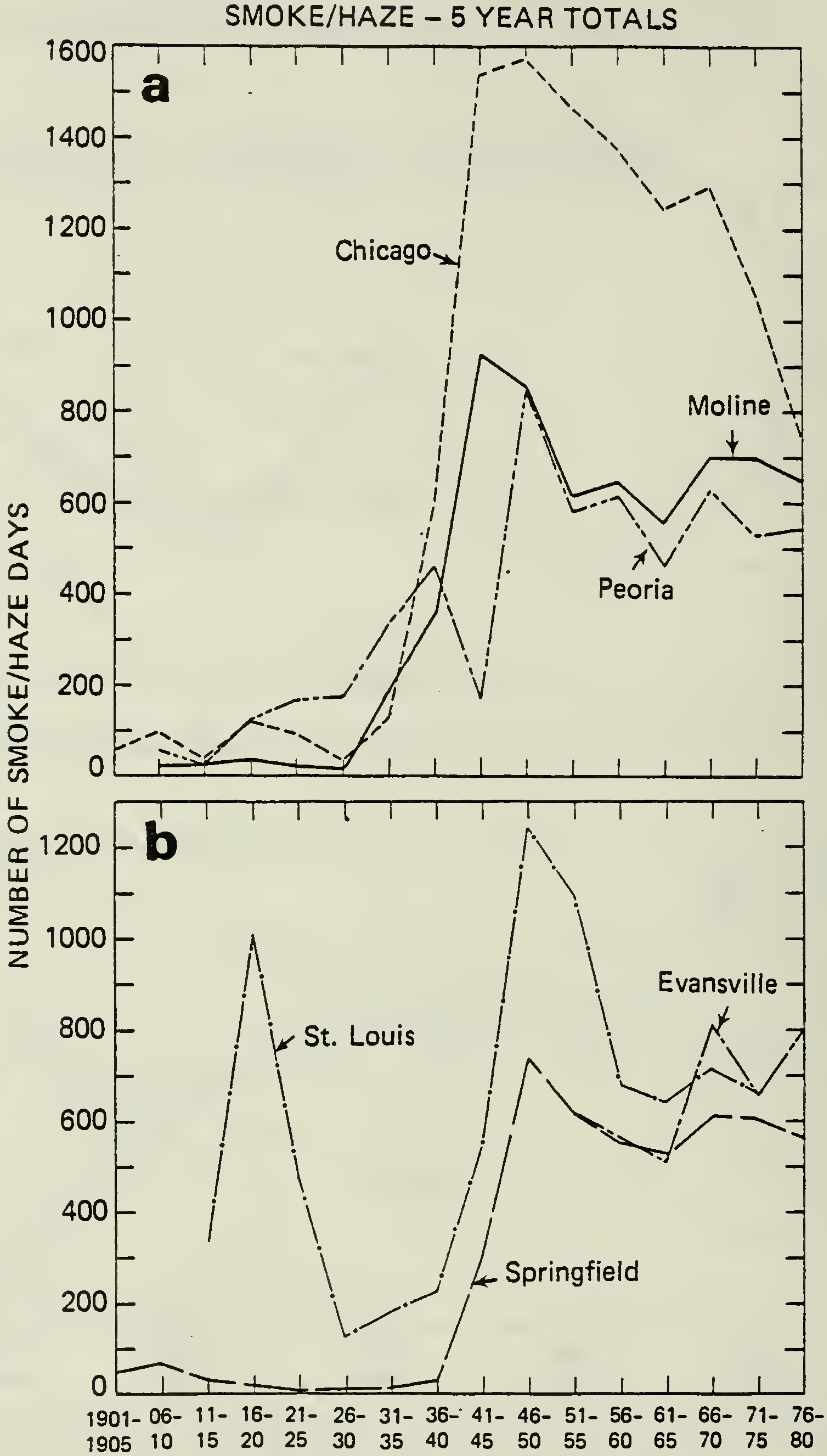


FIGURE 20. Frequency of days (per 5-years) of smoke/haze conditions.



period, with major peaks achieved in 1946-1950 at both stations. Thereafter, general decreases are shown. Comparison of the smoke/haze day curves of the northern Illinois stations with those for visibility shows some agreement. However, Chicago showed a major decrease in smoke/haze days during the 1951-1980 period without a corresponding major increase in visibility until 1976-1980. A recent decrease in smoke/haze days was evident at Moline and Peoria and visibility at these two stations increased during 1951-1980.

The visibility of southern Illinois stations decreased during 1951-1980, but smoke/haze days for two of these stations (See Figure 20b) also showed decreases (Springfield and St. Louis). Hence, there was not an agreement; that is, visibility decreased but without an increase in smoke/haze days.

Another factor that can affect visibility and is indicative of certain climatic conditions (very dry and windy) is the number of days when dust is recorded in the atmosphere. Figures 21a and 21b present 5-year values of dust days, with very low values during the 1901-1930 period at all stations. The highest values on record were obtained in the 1930s and are associated with the major drought of that time. St. Louis also shows high values during the major drought period of 1951-1955. Fluctuations and trends found in days with dust in the atmosphere are not reflected in the visibility values. In the recent 10 years, an uptrend in dust is also exhibited at all stations except Peoria. This is largely due to farm practices (Changnon, 1982a).

Severe Local Storm Conditions

Thunderstorm frequency, as measured by days when thunder occurred at the first-order stations, was also analyzed. The 5-year totals of thunder days at six stations are plotted in Figures 22a and 22b. Basically, the northern Illinois stations exhibit slight upward trends in thunderstorms, whereas the southern stations show downward trends in thunderstorm day frequencies. The hail day frequencies have similar trends. The frequency of days with high winds also agree (Changnon, 1980).

Tornadoes are another form of severe local storm conditions which were studied for their temporal differences. Changnon (1982b) made a study of the temporal fluctuations of tornadoes in Illinois. A major conclusion is that the frequency is highly dependent upon the observational conditions being employed by the National Weather Service. The number of tornadoes in Illinois show marked increases after changes in recording procedures during the early 1950s and again in the 1970s (See Figure 23). However, the frequency of tornado days when deaths occurred shows slight fluctuations but no general trend up or down with time during 1901 to 1980.

Wind Directions

The prevailing wind direction in each month (1901-1980) was recorded at six stations. Station relocations (city to airport) occurred at all first-order stations (generally in the 1940-1943 period). However these are not considered to have produced marked differences in wind directions, except possibly at Chicago. In this paper, data presented are restricted to July, but a more extensive study presents data for other months (Changnon, 1983).

FIGURE 21. Frequency of days with dust per 5-year periods.

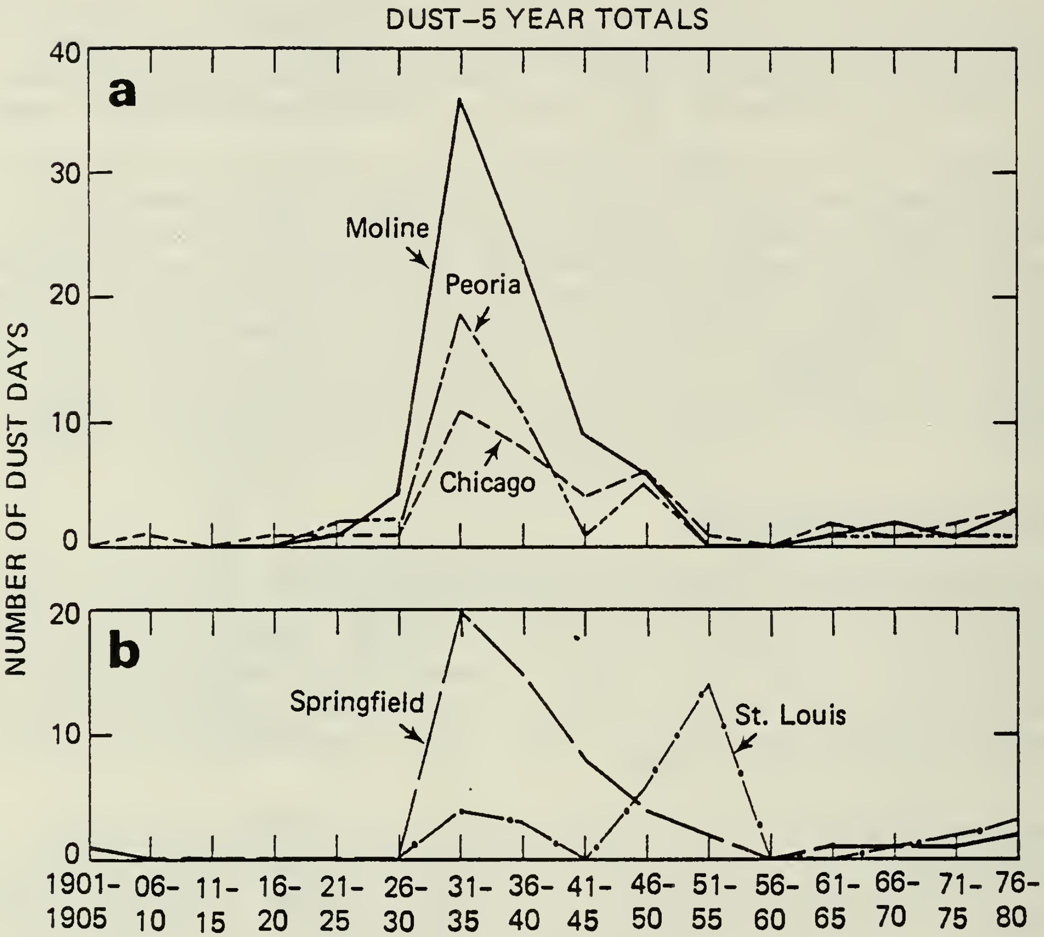


FIGURE 22. Frequency of days with thunder per 5-year periods.

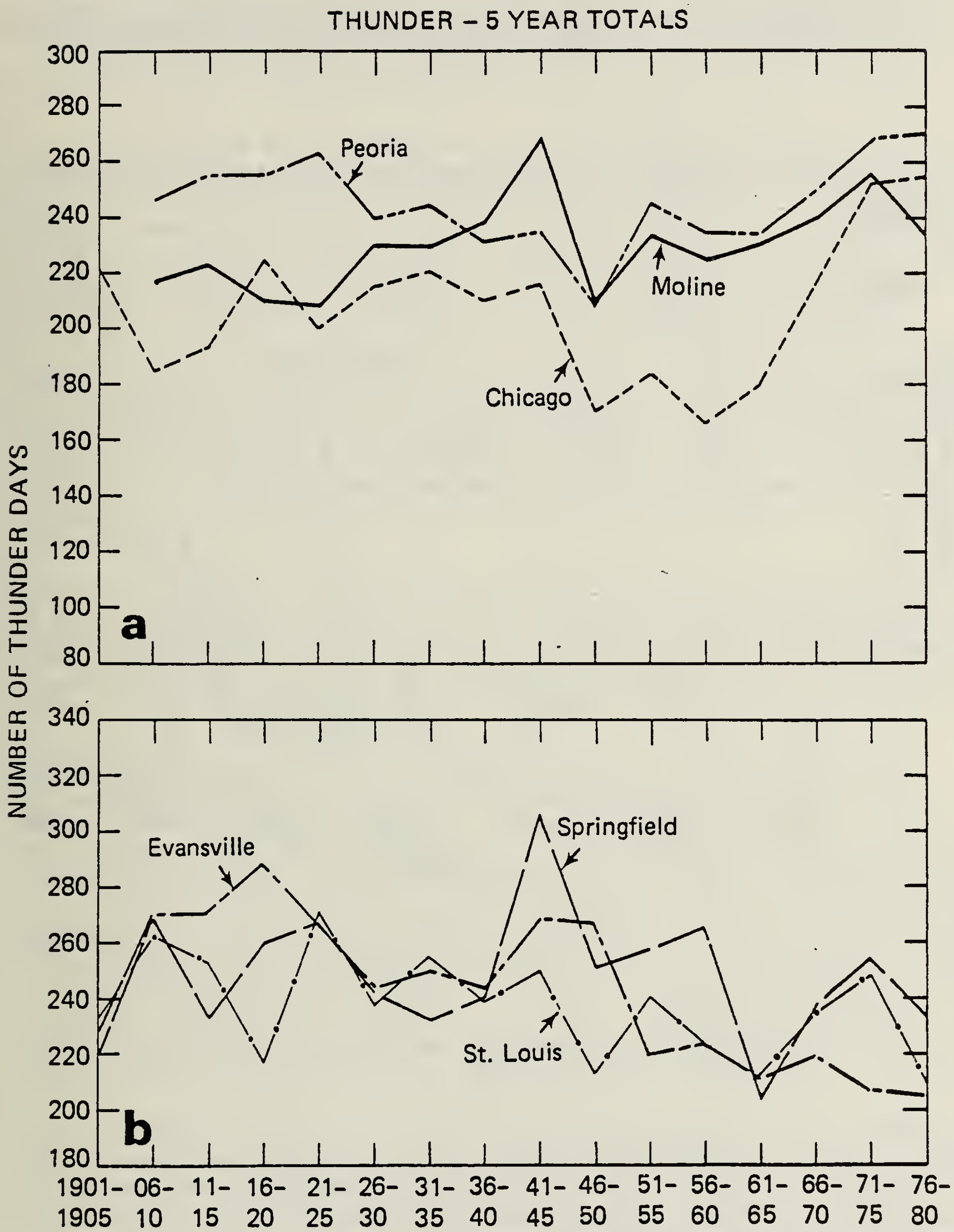
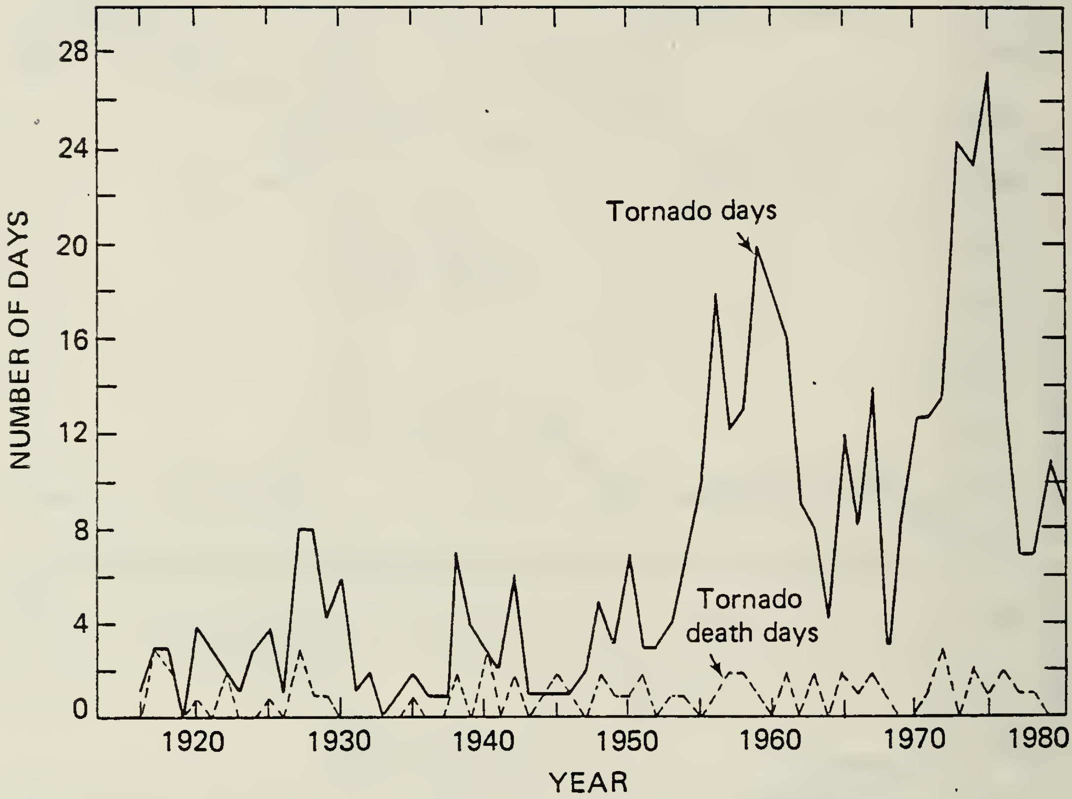


FIGURE 23. Frequency of tornado days and death days caused by tornadoes.



Figures 24a through 24f present the 80-year July wind frequencies for each station. Calculation of all the July directional frequencies reveals that S winds ranked first in central Illinois (Peoria and Springfield), ranked second in the south, and third in the north. SW prevailing winds in July ranked first in both southern and northern Illinois, and second in central Illinois. NE winds ranked second or third in northeast Illinois with E and SSW winds also ranking relatively high.

In 1901-1910, SW winds prevailed in the northern two-thirds of Illinois, with S common in the south (See Figure 25). In the next decade (1911-1920) a major shift occurred with SW prevailing in the south. The SW predominance then covered the southern half of the state from 1921 to 1930 with a diversity of directions to the north. During the next two decades (1931-1950), SW winds in July dominated Illinois. In the remaining three decades (1951-1980) July wind directions in southern Illinois became more diverse.

More major temporal shifts in wind directions were found in January. NW winds prevailed in 1901-1920; then W and S in 1921-1950; then NW and SW were most common in 1951-1980. Temporal shifts in April prevailing directions were minor at the four southernmost stations. They all had S as a prevailing direction in April in most decades. The two northernmost stations exhibited greater temporal change between decades, a mix of northerly and southerly directions.

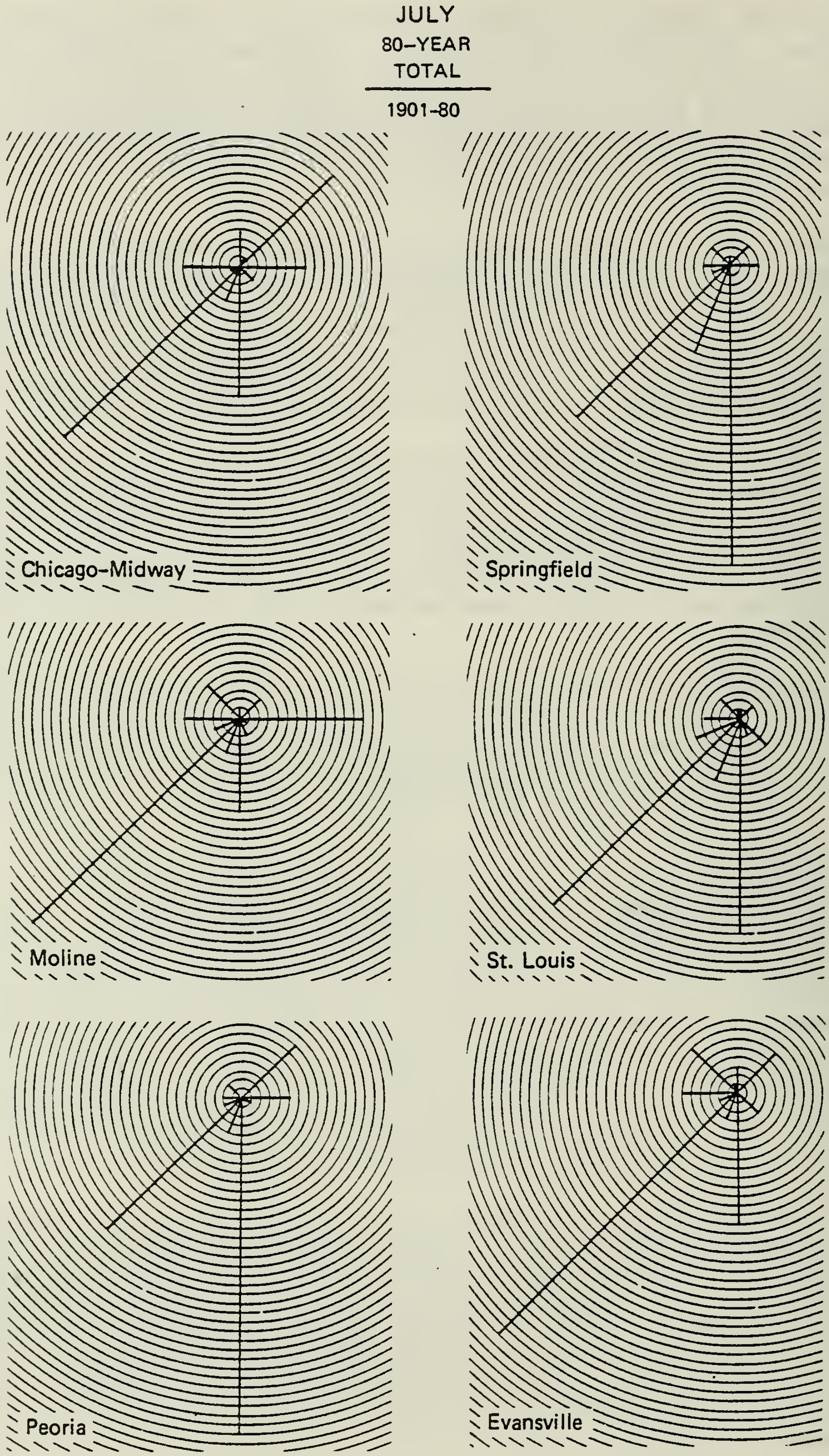
The temporal shifts in prevailing wind direction in October were minor at the four southernmost stations where S or SSW was most frequent in every decade. The two northernmost stations showed greater variations with time. NW and W winds dominated in the first 30 years (1901-1931), with S and SW winds dominant in the last 50 years of this century.

Wind Speeds

Monthly average wind speeds for four months (January, April, July and October to represent the four seasons) were used to study temporal shifts in speeds. The monthly values of six first-order stations were averaged for decades. Critical to this analysis were the sites and heights of the recording anemometers. Sites of the stations from 1901 to their shifts to airport sites (done in the late 1930s or 1940s at most locales) were in city centers, and their heights varied between cities. These are considered in the interpretation of the data. Clearly, the shifts had major influences on the wind speeds; hence the analysis was divided into examination of trends during 1901-1930 (pre-shifts) and to 1941-1980 (post-shifts).

The 1901-1930 January wind speeds at all northern stations showed decreases with time (See Figure 16). St. Louis and Evansville, the two southernmost stations, showed uptrends from 1901 to 1930, indicating a possible climatic difference. In this 30-year period, January winds were most common from the south in southern Illinois, but were commonly westerly or northwesterly in the northern two-thirds of Illinois. The January wind speeds from 1941 to 1980 were different. The four northernmost stations showed slight uptrends (0.5 to 1.5 mph increases in 40 years) whereas southern stations showed no trends, up or down.

FIGURE 24. Prevailing wind direction frequencies for July.



The April wind speeds revealed trends similar to those found in January. During the 1901-1930 period, northern stations showed decreasing speeds, whereas southern stations had uptrends. In the 1941-1980 period, the data for the four northernmost stations show uptrends, as in January, and St. Louis and Evansville show flat trends. Interestingly, the northern stations revealed directional shifts in 1941-1980 and the southern stations did not.

In certain respects, trends found in the July winds were similar to those found in the January and April winds. As shown in Figures 26a and 26b, the 1901-1930 period was characterized by decreases in speed at the northernmost stations (central and northern Illinois). Conversely, speeds at St. Louis and Evansville increase in this same period, suggesting a sharp north-south difference in wind conditions. At these two southernmost stations, prevailing directions had gone from S in 1901-1910 to SW for 1911-1930 (See Figure 25). In the 1941-1980 period, July mean wind speeds at the three northernmost stations (See Figure 25a) all increased somewhat. In the southern half of Illinois, stations all showed a decrease in July winds from 1941 to 1980. During this 40-year period, July wind directions became more diverse, in general, in the southern half of the state (See Figure 25), with prevailing winds being more southerly in the north.

SUMMARY

The data for most climatic conditions in Illinois, and during the 1890-1980 period, reveal moderate to large fluctuations with time and, in many cases, notable trends over part or the entire 90-year period. This is not unexpected, but the results here and in a new document (Changnon, 1983) help provide a comprehensive description of the types and amounts of fluctuations found in most weather conditions. All the data portrayed in this report are located at the Illinois State Water Survey and can be obtained for further studies.

Research at the Illinois State Water Survey (Lamb and Changnon, 1982; Neill, 1981) has shown that conditions in the most recent 5 to 20 years are the best estimate of conditions in the next few years. Thus, the climatic conditions of the last 5 to 20 years are important as indicators of the climate conditions most likely during the next few years.

The recent precipitation data, in almost all respects, reveal relatively wet conditions. The 1961-1980 period has had relatively heavy annual precipitation, reflected in more days of precipitation at all levels (ranging from 0.01 inch up to more than 2 inches), more snowfall and deeper snow depths, and more freezing rain days than earlier years. The tendency to a wetter climate was found in all four seasons. The recent reduction in severe droughts provides other evidence of the wetter regime.

Temperatures in the last 20 years also reflect a marked trend toward colder conditions. We find recent and sharp downward trends in annual statewide temperatures, in winter temperatures and in summer temperatures. The decrease in temperatures is more obvious in the maximum than in the minimum

FIGURE 25. Decadal frequencies of July wind directions.

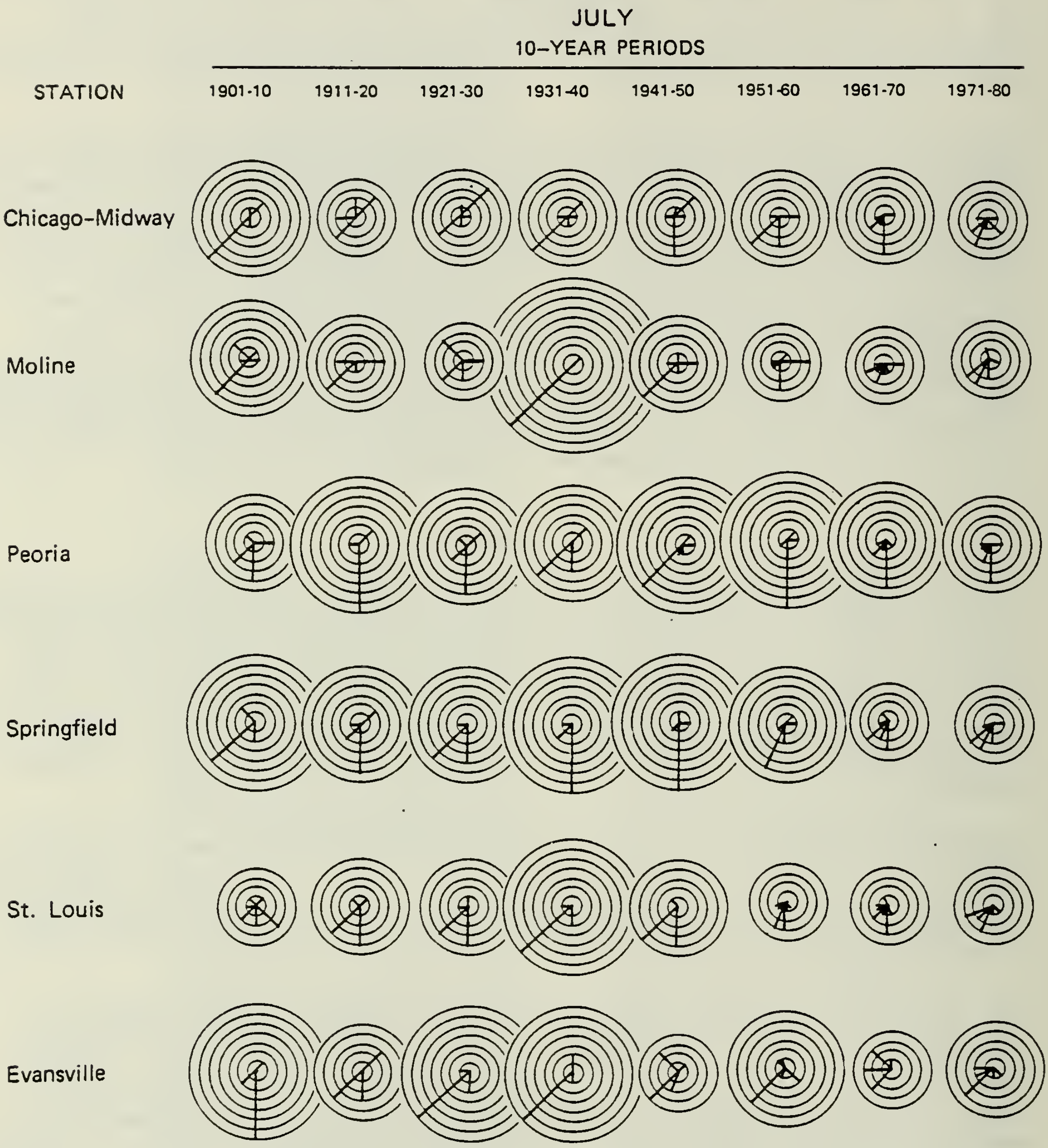
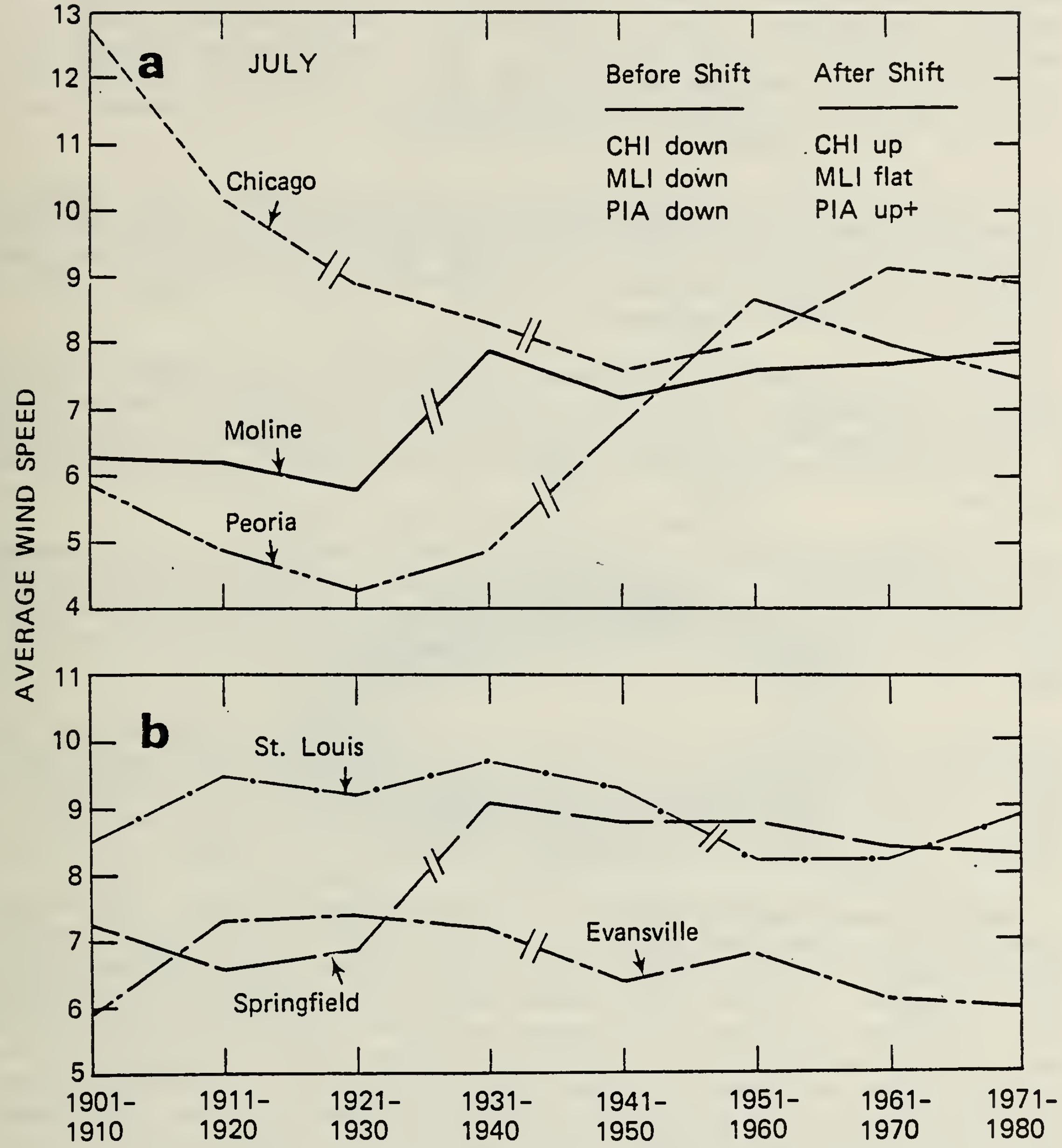


FIGURE 26. Decadal average wind speeds in July.



temperature values, and the colder regime is reflected in fewer extremely warm days and many more extremely cold days. The net effect of greater reduction in maximum temperatures rather than in minimum values is to narrow the difference. An interesting aspect of the recent 20-year temperature conditions is the lack of much change from prior years in the spring and fall seasonal temperatures. The trend toward lower temperatures is found only in the extreme seasons, winter and summer. The slightly warmer springs in the last 25 years have made the average date of last freeze occur slightly earlier than before, producing a slight increase in the growing season length during the last 20 years.

The studies of cloud cover and sunshine support, in general, the temperature and precipitation shifts. Since 1940 there has been a period of increased cloudiness and decreased sunshine and clear skies. These shifts have been particularly marked in the summer and winter seasons. The results agree with the cooler and wetter conditions.

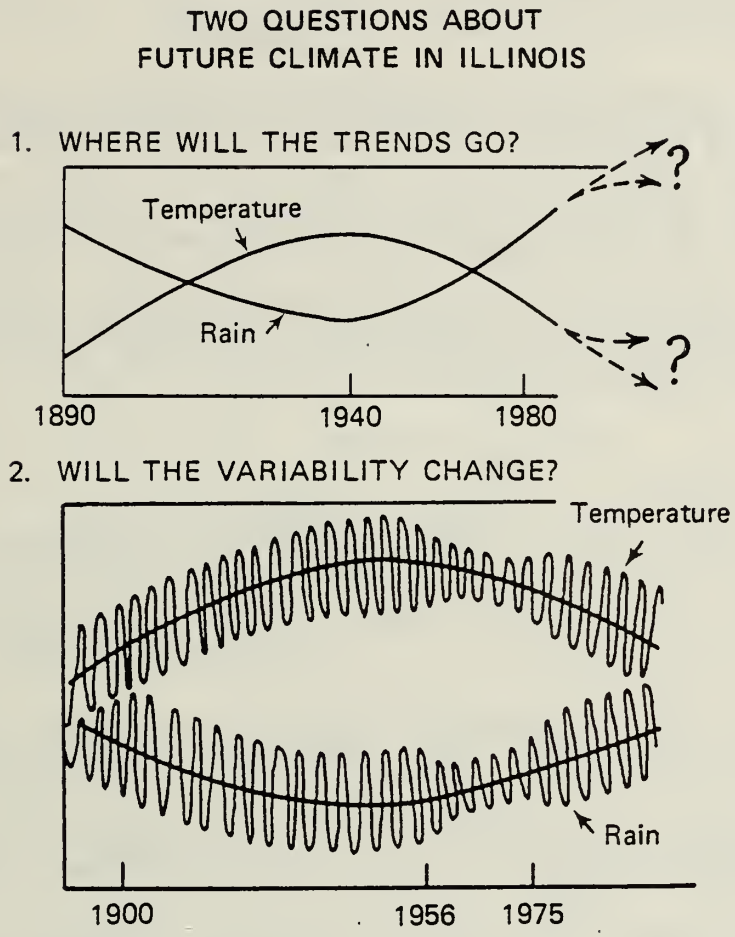
Visibilities have generally decreased, particularly in the summer. The frequencies of days with smoke and haze have decreased, probably reflecting the national environmental protection controls, but the number of days with dust in the atmosphere has increased largely as a result of changing agricultural practices.

Investigations of severe local storms show mixed regional results. Frequencies of thunderstorms, hail and high winds have increased in recent years in the northern half of Illinois, but have decreased in the southern half of the state. There is a slight increase in tornado frequencies in the last 20 years.

Analysis of wind conditions shows recent shifts in the wind directions during January and July, becoming more westerly in January and more southerly in July. There has been little temporal change in wind directions in April and October. Wind speeds have increased the last 20 years in all seasons in northern Illinois and have decreased in all seasons in southern Illinois.

In summary, the climate conditions of the two extreme seasons, winter and summer, have changed considerably during the last 20 years (See Figure 27). This includes 1) more precipitation, including more rain and snowfall and fewer droughts; 2) lower temperatures particularly in winter, and reflected most in maximum temperatures in summer and winter; 3) more cloudy days and less sunshine particularly in summer and winter; and 4) notable shifts in wind directions and speed in winter and summer months. In contrast, the climate changes in the transition seasons have been much less considerable. These two seasons have become slightly wetter, but temperatures have not become markedly warmer or colder relative to earlier years. Very little change in wind directions or speeds has been noted in these two seasons alone.

FIGURE 27. Major climate shifts in Illinois.



REFERENCES

Changnon, S. A., 1980. Climatology of high damaging winds in Illinois. Report of Investigation 95, Illinois State Water Survey, Urbana, 49 pp.

Changnon, S. A., Changnon, D., and P. Stone, 1980. Illinois third consecutive severe winter: 1978-79. Report of Investigation 94, Illinois State Water Survey, Urbana, 31 pp.

Changnon, S. A., 1981a. Midwestern cloud, sunshine and temperature trends since 1901: possible evidence of jet contrail effects. J. Appl. Meteor., 20: 496-508.

Changnon, S. A., 1981b. Changing climate or not, weather extremes cost money. Illinois Issues. pp. 10-11.

Changnon, S. A., 1982a. Causes and implications of record windblown dust conditions during 1981 in Illinois. Circular 151, Illinois State Water Survey, Champaign, 24 pp.

Changnon, S. A., 1982b. User beware: the uptrend in tornado frequencies. Weatherwise, 35: 64-69.

Changnon, S. A., 1983. Climate fluctuations in Illinois: 1901-1980. Bulletin 58, Illinois State Water Survey, Champaign, 88 pp.

Huff, F. A. and J. C. Neill, 1959. Frequency relations for storm rainfall in Illinois. Bulletin 46, Illinois State Water Survey, 65 pp.

Huff, F. A. and S. A. Changnon, 1963. Drought climatology of Illinois. Bulletin 50, Illinois State Water Survey, Champaign, 68 pp.

Lamb, P. J. and S. A. Changnon, 1982. On the best temperature and precipitation normals: the Illinois situation. J. Appl. Meteor., Vol. 20: 1383-1390.

Vinzani, P., 1982. Climate change at Peoria. Trans. Ill. Acad. Sciences, 75: 13-16.

FUTURE CLIMATES: REASONS FOR A COLD OUTCOME

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INTRODUCTION

A mass of evidence exists attesting to the variability of climate, or climate change over many time scales. On the longer scale, oxygen isotope analyses of ocean sediments and glacial ice cores show that air and ocean temperatures have changed by several degrees Celsius over the last tens of thousands of years. Pollen evidence infers several climatic episodes over the last 10,000 years or more. In eastern North America, major vegetation regions of 12,000 years ago were displaced south of their present position by as much as 1,000 km due to the continental glacier over North America. On a shorter time scale, Herron et al. (1981) have presented temperature data for the last ca. 2,000 years with greater detail, reconstructed from a 900 m Greenland ice core.

The instrumental record of the last century or so, too, is indicative of a dynamic climate, i.e., parameters exhibiting temporal variability. This variable nature can significantly affect human activity. The economic impact of temperature and precipitation variability are clearly evident on agricultural production, food prices, the future market, federal agricultural programs, industry, commerce, energy, etc.

This paper will focus on climatic changes within the instrumental record (the last 100 years or so), to identify patterns, likely causes for such variability with particular attention toward causes of cooling, and to estimate what the immediate future might hold. Unfortunately, cause and effect in the atmosphere are usually suggested by association, i.e., when time-series of two parameters, which have been physically associated in the laboratory are shown to co-vary, one is assumed to have caused the response in the other. Such reasoning may be highly suggestive, but cannot prove the allegation, since most atmospheric parameters respond to a complex of forcing functions, rather than simply to one.

WORLD TEMPERATURE SINCE AD 1880

From 1880 to the present, the average annual global temperature increased about 0.5°C until about 1940 (Figure 1) and declined about 0.2°C until the most recent decade when a leveling or a return to warming is suggested. That this curve represents hemispheric temperature trends (even though the temperature data are primarily of continental origin) is supported by a time series of mean sea surface temperature (Paltridge and Woodruff, 1981) from the same years. The sea temperature exhibit similar trends, with reduced amplitude, and with the times of maximum and minimum delayed by some 10 to 20 years form those found in the air temperature record, an expected feature due to the relatively large heat capacity of water compared to that of air.

Interestingly, the temporal trend of mean annual temperature for the Southern Hemisphere is not the same as that of the Northern Hemisphere. This suggests that the cause(s) in each hemisphere may be different, and that the forcing function(s) affecting one hemisphere may be (partially) excluded from the other.

During warm or cold episodes of the last 100 years, or the last 10 years, or the last year, both positive and negative mesoscale anomalies exist. Wahl and Lawson (1970) presented the difference of mid-1800s temperature and precipitation from those of the mid-1900s. They found that the mean annual temperature of the eastern United States was colder 100 years ago than today, but the Rockies and west coast were warmer. Virtually all of the United States 100 years ago experienced somewhat greater precipitation than today. Lawson (1981) constructed mean annual temperature trends from the late 1800s to the present from nine "benchmark" stations within the United States. In general, sites from the Northeast exhibited a similar trend to that of the hemisphere, although the magnitudes were different. The temperature trends of the remainder of the country showed little correlation to each other or to that of the hemisphere. The lesson to be learned is that all regions do not uniformly warm or cool with the global trend.

CAUSES OF GLOBAL TEMPERATURE CHANGE

The temperature of the earth-atmosphere system reaches an equilibrium value when the radiation losses from the system equal the radiation gains during a given time. Hence any phenomenon which modifies the energy input or output can conceivably modify the earth's mean temperature, and the distribution of positive and negative anomalies. An increase or decrease in solar output, a change in the constituents of the atmosphere, or a change to the radiative and absorptive properties of the earth's surface could contribute to a new equilibrium temperature.

Changes in Solar Output

Changing solar strength is sometimes invoked to explain changing earth temperature. Over very long time scales, solar variability may indeed be a cause, but neither measurements from the earth's surface over several decades, or from the Solar Maximum Mission satellite observation from the last two years show substantial change, the latter being limited to ±0,35 percent.

Changes to the Energy Characteristics of the Earth's Surface

The equilibrium temperature of a given location is in part dependent on the albedo of the receiving surface as well as its thermal admittance and heat capacity. If the surface has been changed, either through loss of moisture or vegetation, or has been covered by tarmac or concrete, the thermal characteristics of the surface may be altered. There is little doubt that artificial surfacing of large urban areas changes the thermal characteristics from those of a natural surface. Moreover, the changes to the thermal and precipitation environment of a large metropolitan area can be traced downstream from the urban center for several tens of kilometers (Changnon et al., 1981). Although the impact of an urban area is significant to the surrounding rural

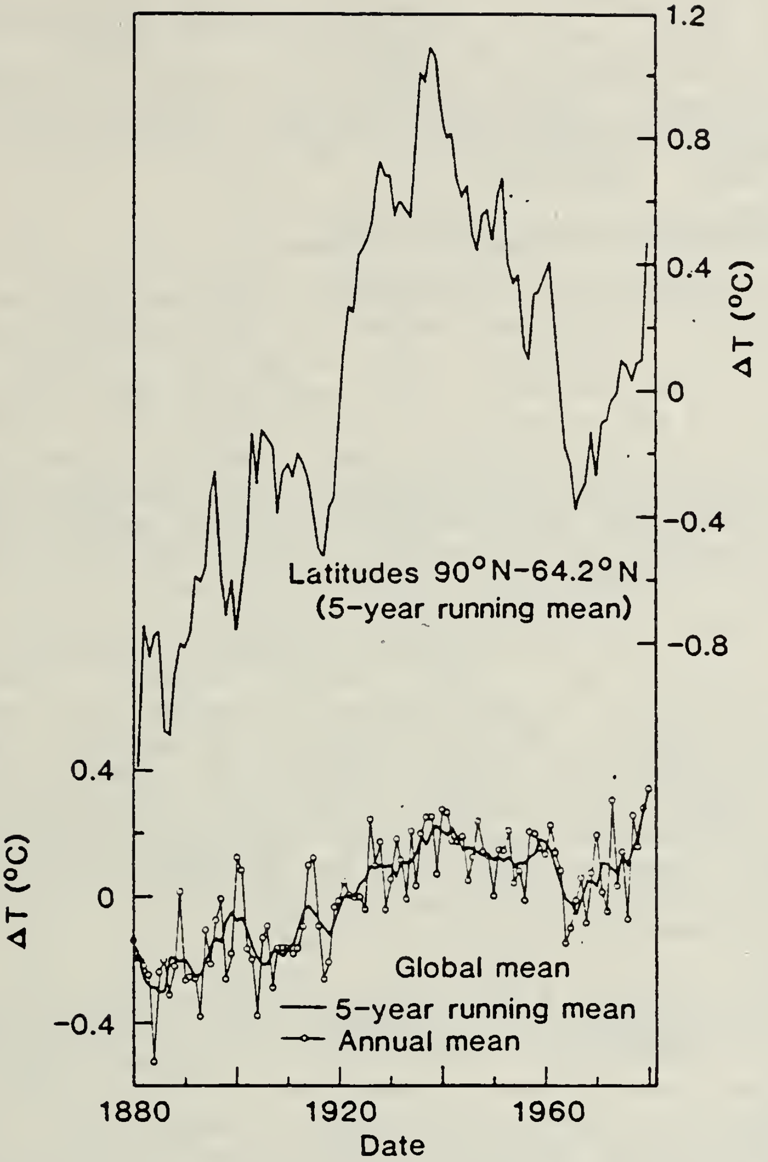

Figure 1

Mean annual temperature from 1880 to the present for high latitude Northern Hemisphere, and for the globe (Hanson et al., 1983).

area, the combined impact of all metropolitan areas upon global temperature is probably insignificant.

A change in the availability of large scale surface moisture permits greater or less use of radiant energy for evaporation. For example, if near-surface soil moisture is decreased, less energy will be used for evaporation, and hence more radiation is available for heating. However, it is difficult to imagine changes of surface moisture sufficient in areal extent or magnitude to affect hemispheric temperature.

Changes to Atmospheric Gaseous Constituents

Of the major constituents of the atmosphere, the concentrations of carbon dioxide and argon are increasing whereas that of stratospheric ozone is apparently decreasing. Argon plays little or no part in climate. Carbon dioxide and ozone, on the other hand, are of particular importance since they both play a role in the greenhouse effect. Both gases are relatively transparent to short-wave, solar radiation (which therefore freely passes through the atmosphere to heat the earth's surface), and are relatively opaque to terrestrial, longwave radiation (thereby inhibiting outgoing radiation). Of the two gases, carbon dioxide plays the major role because of its higher concentration and the magnitude of its impact on the greenhouse effect.

The concentration of atmospheric carbon dioxide has increased from approximately 260 ppm (Barnola et al., 1983), which is thought to represent the pre-industrial concentration, to about 350 ppm at present. The increasee is due to the burning of fossil fuels, deforestation and the natural decay of carbon-containing compounds. The warming from the latter 19th century until about 1940 is generally attributed to an increase in atmospheric CO_2, and radiation modeling generally supports the magnitude of observed temperature change. Present estimates suggest that the concentrations of CO_2 will increase to about 600 ppm within the first few decades of the 21st century with a related temperature increase of 2 or 3°C.

In addition to the concentration of carbon dioxide, the greenhouse effect also responds to concentrations of methane, freon, mitrous oxide, carbon tetrachloride, methyl chloroform, trophospheric ozone, and stratospheric water vapor, all of which participate to some extent in the greenhouse effect. Though the influence of each of these gases on temperature is small by itself, the combined effect of all of them appears to be about equivalent to that of carbon dioxide (J.T. Peterson, pers. com.). Since they are all currently increasing, their impact will be studied with continuing interest.

The downturn in temperature subsequent to 1940 (Figure 1) is of interest because atmospheric CO_2 continued to increase in concentration from the end of the 19th Century to the present which should have supported warming. The observed cooling since 1940 has been attributed by some to a lag in the temperature response of the atmosphere, or to an increase in atmospheric turbidity which masked the warming from CO_2. Increased turbidity could be of natural causes (volcanoes or wind disturbance), or human activities (industrializtion, construction, agriculture, etc.). Potter et al. (1981), and Bryson (1974) both claim that the human impact on planetary albedo

through aerosol injection has been minimal, thereby implying that increasing atmospheric aerosol is largely the result of volcanic or other geophysical phenomena. Indeed, the enhanced volcanic activity of the last few decades supports this claim (see Figure 2).

When modeling mean hemispheric temperature as a function of sunspots, volcanic activity and atmospheric CO_2, Guilliland (1982) found that the most variance (87 percent) of the 100-year Northern Hemisphere temperature record was attained only when the volcanic record was included. Robock (1979) regressed mean temperature against Lamb's dust veil index (a measure of volcanic eruptions), carbon dioxide concentration, and sunspots, and also found that most of the variance in the temperature time series was explained by the dust veil index. He concluded that CO_2 had had no significant effect on temperature as of 1979.

Atmospheric Aerosols and Turbidity

A turbid atmosphere depletes the strength of solar radiation received at the earth's surface through reflection, scattering and absorption at a higher altitude. There are both direct (ash) and indirect products from these sources. An example of the latter: a volcano may produce an aerosol composed of sulfur dioxide, which enters into a photosensitive reaction, producing sulfuric acid. The eruption of el Chichon is an example where the gas component was of greater consequence than the ash.

Atmospheric aerosol measurements are few in number, and are available from only a few sites. Petit et al., (1981), studied the concentrations of zinc, chlorine, sodium, aluminum and microparticles from about 30,000 to about 2,000 years ago, determined from an Antarctic ice core in which the elements had been deposited and preserved. Concentrations of all five parameters exhibited maxima between about 23,000 and 15,000 years ago, i.e., during maximum Wisconsinan glaciation. Whereas sodium and chlorine are of oceanic origin, the source of zinc, aluminum and microparticles is thought to be continental. Because both continental and oceanic aerosols increased during maximum glaciation, the authors suggest that these increases are the result of enhanced wind and aridity, and are therefore a <u>consequence</u> of a glacial climate rather than a cause.

On a shorter time scale, Davitaia (1965) presented the dust concentration preserved in a continental glacier from the Caucasus Mts. from about 1750 to 1950. He suggested that this record resulted form atmospheric deposition, and therefore is a record of large-scale atmospheric aerosol loading. Concentrations were about 20 mg/l from the early part of the record until about 1930, about 80 mg/l during the 1930s and 1940s, and rose to about 240 mg/l during the 1950s, a 12-fold increase from the earliest years. Wendland and Bryson (1970) suggested that the downturn in hemispheric temperature after 1940 may have resulted from this abrupt increase in aerosol.

Hammer et al. (1980) have inferred volcanic activity back to about A.D. 550 based upon the acidity preserved in an ice core from central Greenland. They also refer to a similar time series from a Camp Century core reaching back to about 10,000 years ago. Several events of high acidity (frequent or large

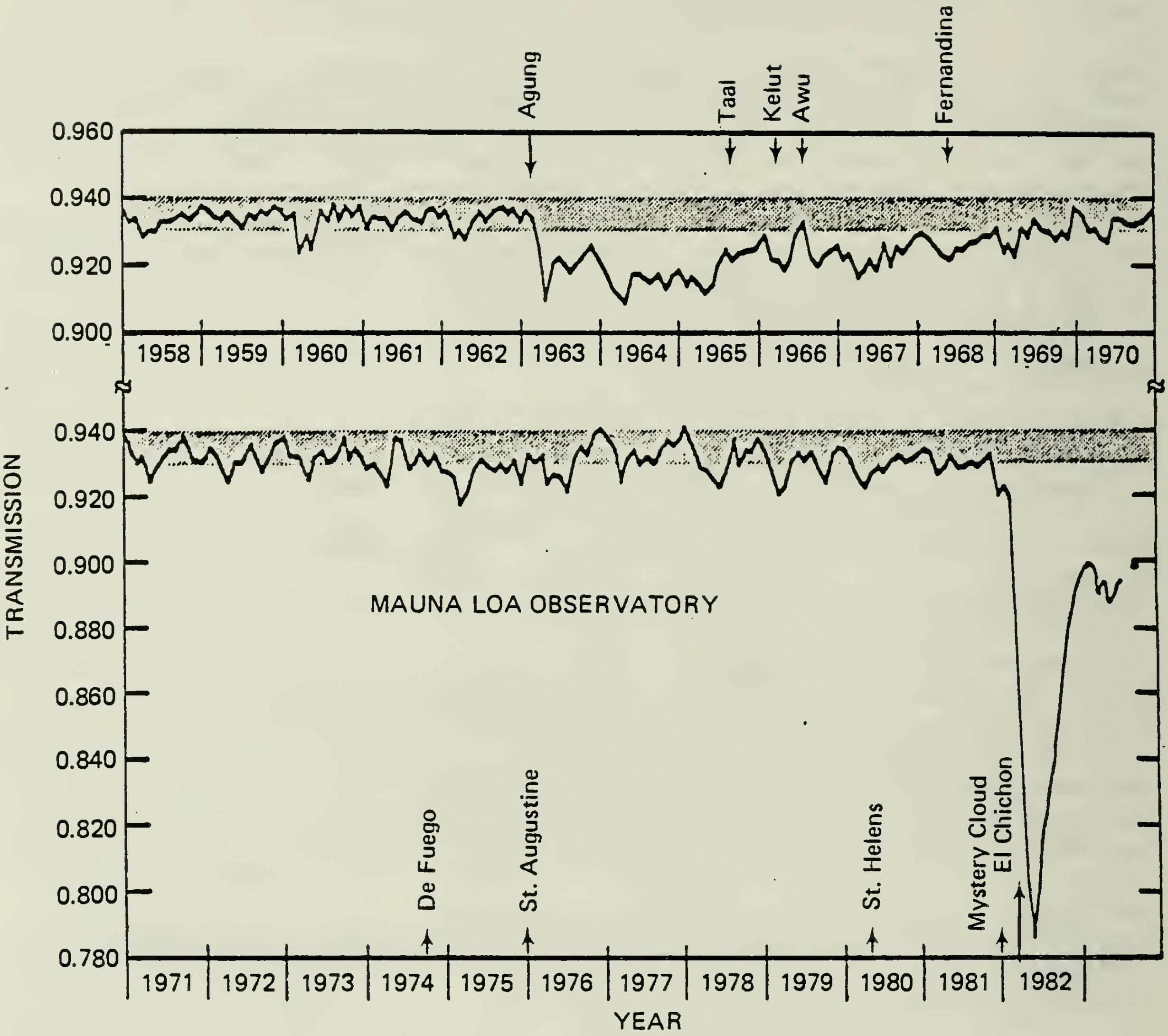

Figure 2

Monthly mean atmospheric transmission measured at Mauna Loa Observatory, Hawaii, with significant volcanic eruptions noted (B.G. Mendonca, pers. com.).

magnitude volcanic eruptions) were identified in the time series, with a notable reduction in acidic volcanic events between about 7,500 and 5,500 years ago (roughly coincident with the warmest episode of the Holocene). Interestingly, this record showed no increase in acidic volcanic events during the most recent decades as did the turbidity record of Davitaia. Herron and Herron (1983) present an acidic profile which indicated the highest sulfate concentration at about 1783 (apparently related to the Laki eruption). Although this profile indicated the greatest acidic concentration during the quiescent episode of Davitaia's turbidity record, these need not be contradictory reports, since one records gaseous eruptions and the other ash eruptions.

Bryson and Goodman (1980) calculated mean annual aerosol optical depth from 1880 to 1978 based on 42 stations between 20 and 65°N latitude. They show a correspondence between an increase in optical depth from ca. 1940 to 1970 and an increase in the frequency of large magnitude Northern Hemispheric volcanic eruptions.

Atmospheric aerosol concentration may be inferred form atmospheric transmissivity records for recent decades from locations far from aerosol point sources. Mendonca et al. (1978) presented mean monthly atmospheric transmission of normal incidence solar radiation from 1958 through 1977 at Mauna Loa Observatory, Hawaii. An updated version is shown in Figure 2 (Mendonca, pers. com.). Although the transmissionvaries from about 0.94 to 0.91, there is no apparent trend in the 20 year record. Of more interest however, is the fact that transmission decreased noticeably after major volcanic eruptions. After the eruption of Mount St. Helens in 1980 decreased atmospheric transmission by only 1.5 percent, whereas the eruption of el Chichon produced a 15.1 percent reduction! Although Mauna Loa may be less sensitive to eruptions at some latitudes than others, the difference in transmission reduction between el Chichon and other major eruptions of the past several decades is notable, and that of el Chichon is probably significant to earth temperature.

Reconstructions purported to represent global atmospheric turbidity have appeared, with varying degrees of similarity. Much work must be done to define the areal scale for which a reconstruction is representative. The impact of short-term wind-blown dust events on visibility over significant portions of the earth are shown by the extensive plumes identified by satellites. A recent report over the open Atlantic Ocean showed concentrations similar to those over rural continental areas (Andreae, 1983). Persistent Arctic haze, containing carbon soot, sulfates and organic carbon, has been observed to altitudes of 8.5 km.

IMPLICATIONS FOR FUTURE CLIMATE

One must indeed be cautious when applying the past discussion to likely future temperature trends. It is easy to accept the possible causes and estimate the direction of temperature change of each. It is quite another matter, however, to estimate the magnitude of a change due to a complex of causes. Nonetheless, some simple statements are possible within the confines of our understanding of the atmosphere.

With hemispheric cooling, some areas would still warm, whereas others would cool relative to the hemispheric mean. To suggest how these patterns might be spatially arranged, Wigley et al. (1980) produced a chart showing differences between the five warmest and five coldest years from 1925 to 1974. Although they presented the data to suggest likely warm CO_2 scenarios, by reversing the signature, we obtain cool scenarios of equal credibility. As one might expect from the heat properties of land and water, the greatest cooling is projected over high-latitude continents, less cooling over mid-latitudes, with slight warming in the sub-tropics.

After the short-term impact of el Chichon, warming from CO_2 should be unmasked. Some expect that such warming will be realized over the next several decades, at least into the first two or three decades of the 21st century.

On the very long term, changes to the orbital parameters of the earth about the sun will lead to warmer summers and cooler winters, reaching a maximum difference about 9,000 years from now. The change will be perceived within a few thousand years and will result in greater temperature contrast between summer and winter.

In summary, atmospheric aerosols represent the most likely cause for cooling. The coincidence of volcanic eruptions with reduced atmospheric transmissivity (clarity) during the last two decades supports such a relationship. The contribution of human-induced aerosols on global temperature is currently unknown. Definitive statements on future global temperature therefore, are highly dependent on magnitude and frequency of volcanic events.

REFERENCES

Andreae, M. O., 1983. Soot carbon and excess fine potassium: Long range transport of combustion derived aerosols. Science, 220: 1148-1151.

Barnola, J.M., Raynaud, A. Neftel and H. Oeschger, 1983. Comparison of CO_2 measurements by two laboratories on air from bubbles in polar ice. Nature, 303: 410-413.

Bryson, R.A., 1974. A perspective on climatic change. Science, 184: 753-760.

Bryson, R.A. and B.M. Goodman, 1980. Volcanic activity and climatic changes. Science, 207: 1041-1046.

Changnon, S.A., Jr., R.G. Semonin, A.H. Auer, R.R. Braham, Jr., and J.M. Hales, 1981. METROMEX: A review and summary. Meteor. Monog., 18: 1-181.

Davitaia, F.F., 1965. Possible influence of the atmospheric dust on the regression of glaciers and warming of climate. Trans, Soviet Acad. Sci., Geogr. Ser. No. 2, 3-22.

Guilliland, R.L., 1982. Solar, volcanic, and CO_2 forcing of recent climatic changes. Clim. Change, 4: 111-131.

Hammer, C.U., H.B. Clausen, and W. Dansgaard, 1980. Greenland ice sheet evidence of post-glacial volcanism and its climatic impact. Nature, 288: 230-235.

Hansen, J., D. Johnson, A. Lacis, S. Lebedeff, P. Lee, D. Rind, and G. Russell, 1983. Reply to Comments on earlier paper. Science, 220: 874-875.

Herron, M.M., S.L. Herron, and C.C. Langway, Jr., 1981. Climatic signal of ice melt features in southern Greenland. Nature, 293: 389-391.

Herron, M.M., and S.L. Herron, 1983. Past atmospheric environments revealed by polar ice core studies. J. Hydrol. Sic., 28: 139-153.

Lawson, M., 1981. Spatial analysis of secular temperature fluctuations. J. Clim., 1: 325-332.

Mendonca, B.G., K.J. Hanson, and J.J. DeLiusi, 1978. Volcanically related secular trends in atmospheric transmission at Mauna Loa Observatory, Hawaii. Science, 202: 513-515.

Paltridge, G., and S. Woodruff, 1981. Changes in global surface temperature from 1880 to 1977 derived from historical records of sea surface temperature. Mon. Wea. Rev., 109: 2427-2434.

Petit, J-R., M. Briat and A Royer, 1981. Ice age aerosol content from East Antarctic ice core samples and past wind strength. Nature, 293: 391-394.

Potter, G.L., H.W. Ellsaesser, M.C. MacCracken and J.S. Ellis, 1981. Albedo change by man: Test of climatic effects. Nature, 291: 47-49.

Robock, A., 1979. The "Little Ice Age." Northern Hemisphere average observations and model calculations. Science, 206: 1402-1404.

Wahl, E.W., and T.L. Lawson, 1970. The climate of the mid-nineteenth century United States compared to the current normals. Mon. Wea. Rev., 98: 259-165.

Wendland, W.M., and R.A. Bryson, 1970. Atmospheric dustiness, man and climatic change. Biol. Conser., 2: 125-128.

Wigley, T.M.L., P.D. Jones and P.M. Kelly, 1980. Scenario for a warm high -CO_2 world. Nature, 283: 17-21.

FUTURE CLIMATES: REASONS FOR A WARM OUTCOME

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I think the message is clear by now, that whether the atmosphere is cooling or warming, whether the heat balance is positive or negative, depends on our time scale. If we look on a very long time scale of tens of thousands of years, we obviously have had both very large warmings and very large coolings; and the climate has fluctuated between ice ages and interglacials. However, I'm going to restrict myself to a process that's expected to warm the earth, as the title implies, and the time scale that we will be looking at has to be only a couple of centuries or less. In fact, I'll be dwelling mostly on the next few decades.

In order to understand what changes may occur in the next few decades we ought first to know about the natural causes of climate change, and I'm grateful to Wayne Wendland for having covered the natural causes of climate change very well. Volcanic activity is one of the causes, and solar activity is another that operates in the time scale that we're talking about.

Regarding volcanoes, it is stratospheric dust, really sulfate particles, from big eruptions that cause a cooling. Theoretically they can cause a cooling on the order of a 0.5° Centigrade, and this can last for a few months or maybe more than a year. There have been a number of very big eruptions in the past, and we have studied the record. Although I think Helmut Landsberg is a little skeptical of this, I believe that some of the analyses do show that, if you take the largest eruptions, there has been a small but significant cooling on a global average in the months following each eruption. It doesn't do any good to look at just one station, of course.

The climatic influence of solar activity is a much more controversial matter. We know from many centuries of looking at the sun since the invention of the telescope that sunspots come and go, and that there is a remarkably regular 11- and 22-year periodicity in the sunspots. It's known as the sunspot cycle. I don't think anybody can deny the existence of the sunspot cycle. More recently a kind of amplitude modulation effect at an 80-year period, known as the Gleisberg Cycle, has been identified. Thus, the amplitude of the 11-year cycle waxes and wanes at this longer period.

But the question is: Do these changes in solar activity as measured by sunspots really reflect a change in the total output of the sun? It's the so-called "solar constant" that determines the temperature of the earth. Theoretically a change of only about 0.10 percent in the output of the sun can cause on the order of 0.10° Centigrade change in the mean surface temperature, and this is the magnitude of the temperature changes that we've seen from volcanic eruptions, for example. We now have satellite measurements above the atmosphere which show that the sun does, in fact, change its

output over periods of a week or two. We haven't had such sensitive measurements from satellites long enough to know whether the 11-year sunspot period governs a change in the output of the sun. We haven't any direct observations of that yet. The nearest we can come to it is to look at the temperature record and seek a correlation between Northern Hemisphere mean temperature and solar activity as measured by sunspot cycles. A number of people have looked at this, Douglas Hoyt, for one. More recently the group in New York led by James Hansen at the Goddard Institute of Space Studies and Ron Gilliland at NCAR have looked more closely at this correlation between global temperature and solar activity, and they find that they can indeed explain some of the wiggles in the temperature curve. But that's a subject that I'll come back to later.

These are the <u>natural</u> causes of climate change, and I think Wayne Wendland in particular has discussed them very well. That makes it easier for me, because I'm going to dwell on just one relatively new cause, namely, <u>mankind</u>. We do a lot of things to change our environment on many scales. I am interested in the things that we're doing that affect the climate on a global scale. There are four main things that we can think of.

First of all, of course, mankind has been changing the surface properties of the planet. One can illustrate the effect that we have had on the surface by innumerable good Landsat pictures from space. For example, there is the famous picture of Mt. Egmont on the north island of New Zealand. They put a fence around this beautiful volcanic peak and made a national park inside the fence. Outside that fence cattle and sheep still graze, and the contrast in vegetation as seen from above is very striking.

Another famous Landsat picture is the one showing the pre-1967 boundary between Israel and Egypt. There was heavy grazing on the Egyptian side and protected terrain on the Israeli side. Several years after the Six-Day War one can still see the boundary from space as a straight line separating desert from protected vegetation. This a good indication of the kind of thing that has happened over very wide areas of the world and which must have affected climate on a regional scale.

Another thing that we do is generate an enormous amount of energy, all of which ends up as heat with very trivial exceptions (like the radio waves that disappear into space). It seems as if we are trying to light up the whole world. The question is: How much energy are we producing relative to the main natural source of energy, which is sunlight? Well, it turns out that it is very little. It's like one ten-thousandth of the total amount of solar radiation that we receive as power at the surface, so we can neglect the emission of heat by mankind as a global problem in the context of climate change.

However, the things that we've added to the atmosphere are a different thing. I'm grateful to Wayne Wendland for having discussed the question of aerosols, which he has looked into a great deal. We are putting enormous quantities of gases and aerosols into the atmosphere, and we will hear later in this meeting about acid rain and the smelly stuff that we put into the atmosphere.

What I'm going to talk about mostly is the invisible and odorless stuff and its global effects.

But first of all I will add a few remarks about industrial aerosols and their global influence. There's no question that in the industrial areas of the world we have put a lot of "crud" into the atmosphere in the form of sulfate particles and carbonaceous particles, and these are usually combined into small particles that absorb sunlight. However, if we look at the geographical extent of this industrial pollution we can see that it only occupies a relatively small faction of the globe - it's a regional effect. Whether it causes a regional warming or cooling is still a matter of debate, but it appears from the observational and theoretical work that some of us have been doing that it ought to cause a warming when it's over a typical surface with a fairly high albedo, and most of it is to be found over the land. When it moves out over the ocean it may cause a cooling then. So, to summarize the climatic effects of anthropogenic aerosols, they are a) small, and b) regional.

The carbon dioxide record and its influence on climate is somewhat less controversial. This is the Mauna Loa (Hawaii) record of carbon dioxide concentration, starting in 1958 and going up to 1980 (see Figure 1). The units of concentration are parts per million by volume (PPMV). The annual cycle is due to the fact that plants take up carbon dioxide from the atmosphere in the spring and summer when they grow, then they put it back in the fall. If we take an annual average it's a little easier to see the trend (see Figure 1a). It was around 314 PPMV or so at the beginning of this record and it's up to 340 PPMV now. It has increased more or less monotonically, but there are wiggles in the curve. Sometimes it goes up faster than at other times. That's a story in itself that I won't have time to get into, but I will just point out that the output of carbon dioxide from fossil fuel burning has been increasing quite steadily for most of that period, so those wiggles must be due to something else. The ocean system is the largest sink for carbon dioxide, so they're probably due to changes in the ocean uptake. But as I say, that's another large subject, one that occupied a full week of discussion in Hamburg last August.

I don't think anybody denies that the steady trend of carbon dioxide shown in Figure 1 is mostly due to the burning of fossil fuels. There's also a contribution to the atmosphere if we cut down a lot of trees and let the debris rot and decay or burn it. This is what happens when we clear forests for agricultural land, something that was going on in a big way toward the end of the last century and in the first part of this century. Now the clearing of forest for agricultural land seems to have slowed a good deal. In the period of the Mauna Loa record (1958 to the present), it was mostly fossil fuel burning that caused the increase.

The rates of use of various kinds of fossil fuels are shown in Figure 2 by Ralph Rotty. The figure shows the annual rate of carbon dioxide emissions (expressed as tons of carbon), and you'll notice that when plotted on a

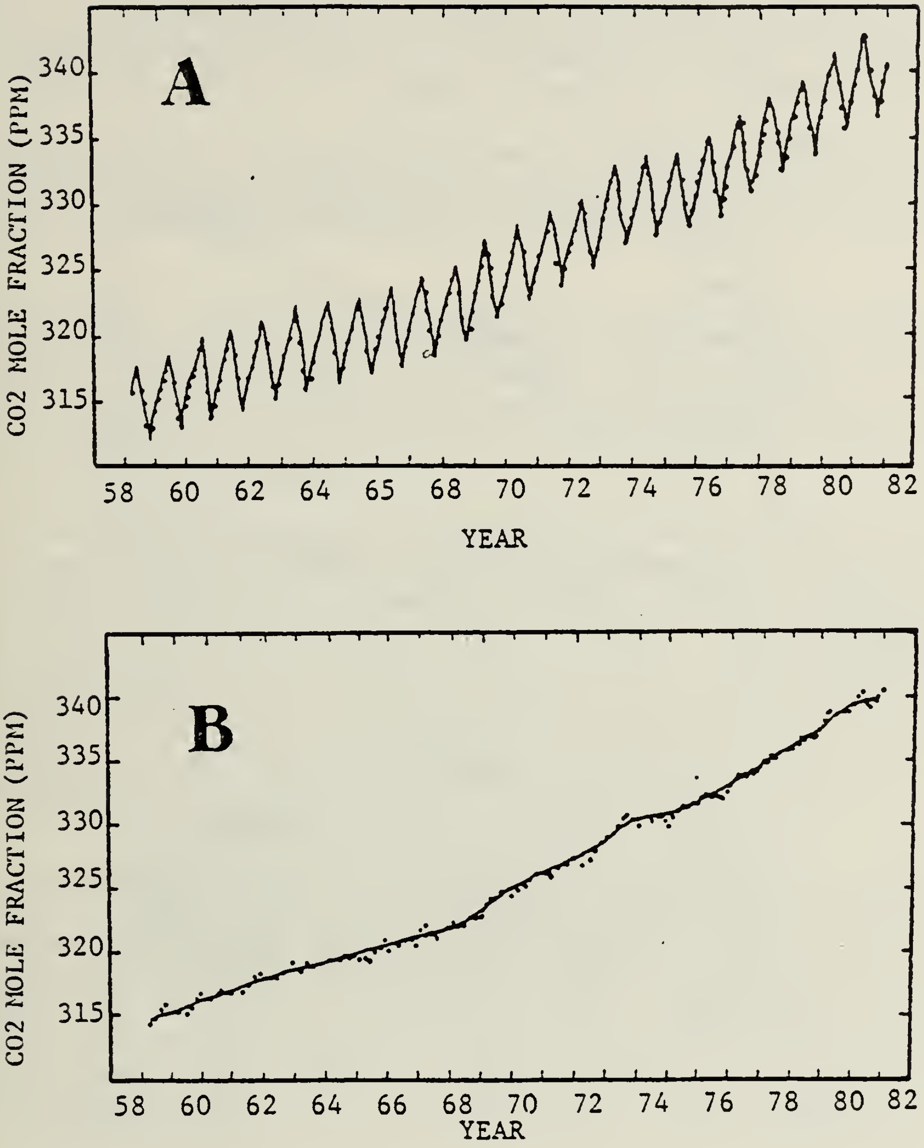


Figure 1

The record of atmospheric carbon dioxide concentration, starting in 1950, measured at the Mauna Loa Observatory on the Island of Hawaii; units are parts per million by volume. (A) shows monthly averages, and the annual cycle caused by vegetation growth and decay in the northern hemisphere is clearly visible; (B) shows running 12-month means, which reveals the variable annual growth rate more clearly. (Source: Keeling, 1982).

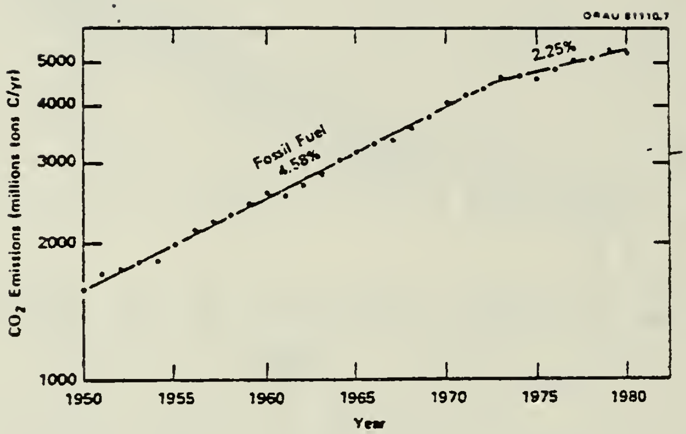


Figure 2

The rate of worldwide carbon dioxide emissions from the burning of fossil fuels and cement manufacturers during the same period as the Mauna Loa record in Figure 1. The units are millions of tons of carbon per year. (Source: Rotty, 1983).

semi-logarithmic graph it's a pretty straight line. That means that it's following an exponential growth, and up to 1973 it was increasing at about 4.5 percent per year. You will all remember what happened in 1973. It was the beginning of the oil embargo by the OPEC countries; it was also the beginning of a worldwide recession. This is indicated by the fact that, while the burning of fossil fuels still increased, it didn't increase as rapidly, and since 1973 it has increased at only 2.25 percent per year.

If we look at a longer time scale going back to the early 1800s or earlier, before the Industrial Revolution got into full swing, the concentration was around 260 PPMV, so we have had about a 25 percent increase in the last 150 years.

The next question is: What's going to happen in the future? It would seem reasonable to expect a continued use of fossil fuels for the next 100 years or more, but at a rate of increase much slower than in the past - or perhaps even starting to decrease in the next 50 years as new energy sources come into play. A doubling of the Pre-Industrial Revolution level may occur in the mid-21st century in any case.

The reason that we're interested in carbon dioxide is, of course, that it affects the heat balance of the earth. We've already been introduced to the idea that carbon dioxide doesn't absorb sunlight but that it does absorb some of the infrared radiation from the surface that would otherwise escape to space. So the effect of adding more carbon dioxide, or any infrared absorbing gas for that matter, is to heat the surface - and, incidentally, to cool the stratosphere. That is often referred to as "the greenhouse effect." We understand the direct effect on atmospheric radiation balance pretty well, because we know the absorption spectrum of carbon dioxide, and its distribution in the atmosphere is fairly uniform.

What we have trouble with is deciding how this change in the radiation interacts with all the other things in the climate system shown in Figure 3. That is the problem. What happens to the climate system? What are the interactions in the climate system? This is the problem being worked on at, for example, NCAR, the Geophysical Fluid Dynamics Lab, the Goddard Institute for Space Studies, and research groups in Great Britain and the Soviet Union. At all of those places climate models are being developed that take into account as many of the components of the climate system as human ingenuity and computer capacity will allow.

Of course, the oceans are a very important part of the climate system and one with which we're having some trouble dealing. How do clouds respond when we change the radiation balance? - a very important question. Last month, in Hamburg, at the meeting of the International Association of Meteorology and Atmospheric Physics a whole week was spent discussing the role of clouds and radiation in the climate system. It appears that the area covered by clouds does not change greatly as we warm up the earth, based on our model studies, but we're not sure of that.

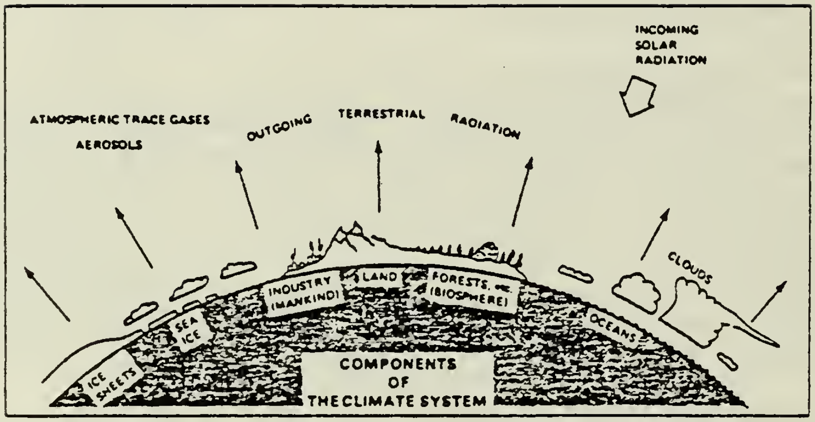


Figure 3

The components of the climate system, all of which interact in one way or another. (Source: Kellogg and Schware, 1981).

Sea ice and snow on land in the polar regions represent another very important aspect of the climate system, because they influence the planetary albedo and their areas will change with a warming or cooling. These are some of the factors that the climate modelers are trying to take into account - and there are several more.

All these components interact, so when we add carbon dioxide to the atmosphere the overall response will depend on these complex interactions. We especially have to take into account one very important "feedback loop." If we warm up the surface a little bit we'll get more evaporation from the oceans, and more evaporation means more water vapor in the atmosphere. Water vapor is also an infrared-absorbing gas, so it will contribute further to the greenhouse warming. The net result is what we call a <u>positive</u> feedback loop, and it amplifies the radiative effect of carbon dioxide alone. The net result of all these feedback loops in the system for a doubling of carbon dioxide from, say, 260 or so parts per million to 520 would be about a 3°C increase in the average temperature of the earth, give or take 1.5°C.

If we use that result and ask what has happened in the last 100 years due to the roughly 15 or 20 percent increase of carbon dioxide in that period we would come to the answer that it's about 0.5°C. This happens to be about the change in the hemispheric or global mean temperature we have actually observed, as shown in Figure 4 by James Hanson and his group at the NASA Goddard Institute for Space Studies. The bottom curve is the global mean, and we notice the warming to a maximum at around 1940, a brief minimum around 1965, and then a warming trend again. In 1981 it actually surpassed the 1940 value, at least for the Northern Hemisphere. I have not seen the results for 1982 yet.

So there's a very suggestive relationship here between a 100-year temperature trend and a theoretical prediction that could account for it in terms of an increase in carbon dioxide. There was a meeting in Moscow organized by the World Meteorological Organization in October 1982, a meeting that I attended as the Rapporteur. The WMO report that resulted asks what reasons we have to suspect that this trend is in fact due to carbon dioxide. I won't go into the details of this complicated argument, but basically it can be boiled down to this: There is a "signal" in the climate record represented by the 0.5°C temperature rise in 100 years. There is also a naturally induced "noise" in the same record of about a couple of tenths of a degree Centigrade for the average temperatures. Thus, if one looks at the situation in a very simple-minded statistical way, a signal-to-noise ratio of over two means that the signal is real (not a random event) with a probability of more than 95 percent. Then if we try to explain some of those wiggles in the record of Figure 5 in terms of volcanic activity and solar activity, we can in a sense reduce the noise - that is, we have "explained" some of the wiggles. Then we get an enormous signal-to-noise ratio, and an even larger probability of the temperature trend being due to carbon dioxide.

As I have said, that's a simple-minded statistical argument and it ignores two very important points. First of all, we're not absolutely sure that our

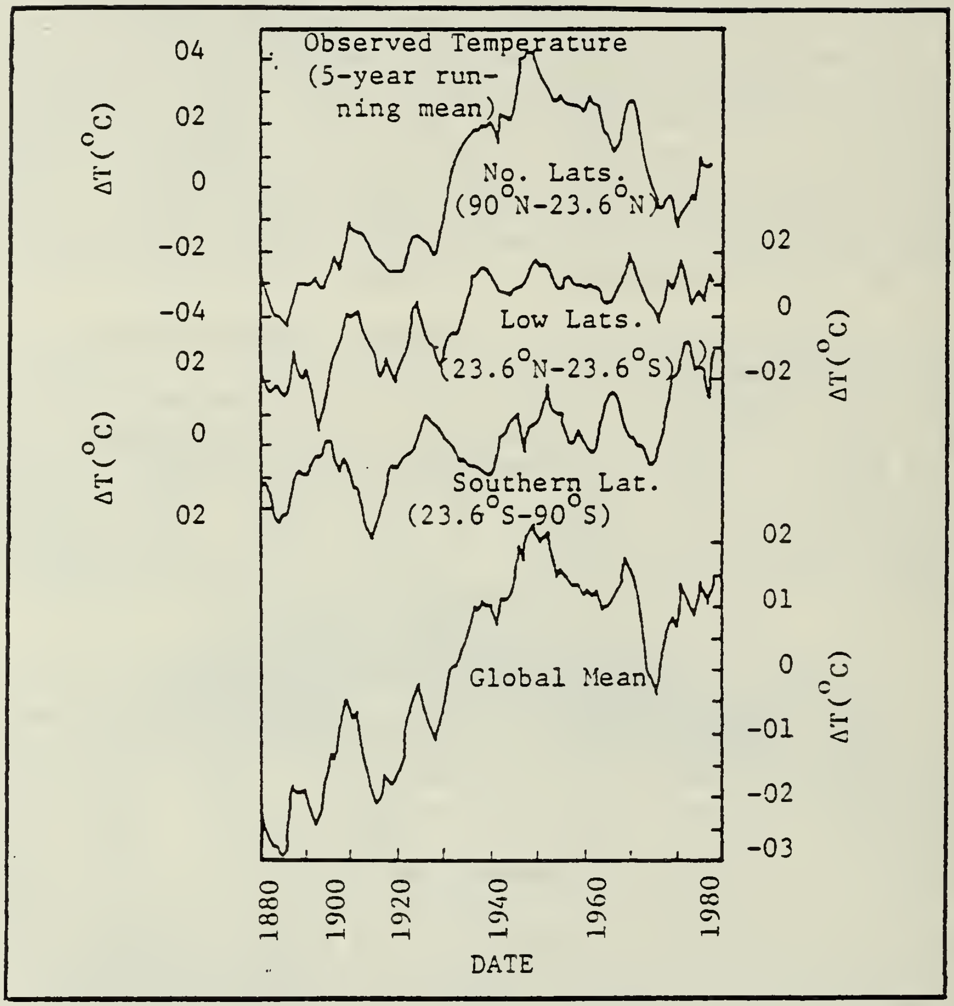


Figure 4

Five-year running mean averages of surface air temperatures for three latitude bands and for the globe, starting in 1880. The 1981 Northern Hemisphere average exceeded the 1945-1950 peak, so we can safely say that the 100-year increase has been about 0.5°C. (Source: Hansen et al, 1981).

theory is right. We can never be absolutely sure, but we now think that it is right because it's been gone over carefully by a good many scientists. Another caveat is that there could be something else that's warming up the world in this 100-year period that we haven't thought of. There have been a few suggestions of other causes, but each has been thrown out because it does not seem to make much sense. One of them, for example, published in Nature last year had to with the warming being due to the change in the magnetic field of the earth. I don't think people who know more than I about geomagnetism take this theory too seriously, but it's significant in that it indicates that we haven't thought about all the other possibilities. I would vote on the warming trend being due to carbon dioxide, but I can't be absolutely sure any more than anybody else can.

Let's put the greenhouse theory, which predicts about a 3°C temperature change for a doubling of CO_2, together with a couple of guesses about how much fossil fuel we're going to be burning in the future. You will recall Figure 2, which showed a 4.5 percent per year increase after 1950, and actually this rate persisted throughout most of this century. Then it fell to about 2.2 percent per year after 1973. Nobody can believe in an exponential growth lasting indefinitely, of course. To avoid a long argument about the future use of fossil fuels, supposing we take a 4 percent per year increase as an upper limit (probably a ridiculously large upper limit), and supposing we take as a lower limit an estimate which says that about 50 years from now, which is roughly the market penetration time for large technologies, we will have stopped our increase and be back to our present rate of burning of fossil fuels. People like Amory Lovins might say that this lower guess is not low enough, but I will use it anyway. These are matters that experts like John Laurmann (who is at this meeting) have thought long and hard about.

If you look into the effects of those upper and lower limits, you can take something in between as being most likely, as shown in Figure 5. By the year 2000, according to this figure, we will have increased the average surface temperature by almost 1°C if we look at the most probable average. That's about twice as much as the 100-year increase that we've already seen. Then by the middle of the next century we'll be warmer by several degrees. In the polar regions the warming will be still larger.

The temperature is, of course, the thing that the climate models calculate directly, because this is what you get as an answer when you do a radiation balance calculation. However, as James King has pointed out very clearly, it's usually precipitation that is more important in determining where things can grow. Precipitation is determined by a much more complicated set of interactions than the temperature. This isn't just a matter of the heat balance. It has to do with where the air comes from, whether it has picked up a lot of moisture along the way, and whether it becomes unstable and dumps that moisture in the form of precipitation. Soil moisture also depends on evaporation, as well as precipitation, which in turn depends on temperature, wind and the kind of surface you have. Thus, precipitation seems to me to be an even more important factor than temperature, although they both have to

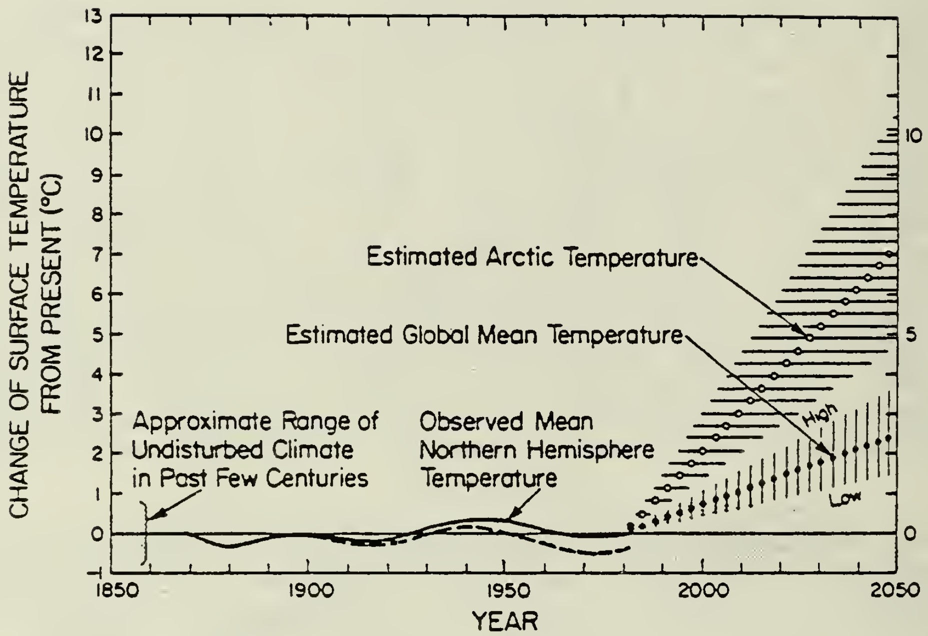


Figure 5

Change of global mean surface air temperature up to the present, and in the future if we follow the "high" or "low" fossil fuel burning scenarios described in the text. The shaded band is the range of temperatures within which the earth has apparently remained for the past several centuries or more. The dashed line is the temperature record that might have been followed if we had not added carbon dioxide and other "greenhouse gases" to the atmosphere. (Source: Kellogg and Schware, 1982).

be taken into account in estimating the effect of a climate change on agriculture and natural ecosystems.

With the idea that precipitation was the most important factor, I tried to get all the information I could gather to put together what I call a "climate scenario." This would describe the areas where I would guess the precipitation would increase and where I would guess that it might decrease as the world grew warmer. The result is shown in Figure 6.

There are three inputs into this climate scenario. One is, of course, our climate models. Our climate models have now gotten good enough so that they do show regional patterns of precipitation and soil moisture, the latter being the difference between rainfall and evaporation.

We can also get information on the regional precipitation and soil moisture by looking at the past. We can look back to the Altithermal Period (discussed several times already), that warm period between roughly 5,000 and 8,000 years ago. A good many paleoclimatologists (I am not one) have studied various parts of the world and have come up with an estimate of whether the Altithermal was wetter or dryer. This is generally based on what things were growing in various places, on the sizes of lakes, on the kinds of soil, on the layering in peat bogs and lake sediments, and so forth. All these are proxy indications of where it was wetter and where it was dryer.

For example, 5,000 years ago and earlier the Sahara Desert was a savanna with people living in it. There have been a number of stories on this in the National Geographic and elsewhere. The place called the Fertile Crescent, that we learned about in our history books as the "cradle of civilization" 5,000 years ago, was really fertile then, and now you can't grow much in the Valley of the Tigris and the Euphrates without irrigation. Another example is northwest India, a place where Wayne Wendland and Reid Bryson have done some of their studies, which is now a desert but it had cities that were thriving before they were covered by sand.

So we have to believe that there were big changes in the distribution of precipitation in the Altithermal Period, and we can put this information together as an indication of what could happen again in the future. There is certainly no guarantee that we'll turn back history and repeat a warm period that will look just like the last warm period, but at least it's an indication of the sort of changes that can happen.

Anomolous years are another input to the development of a climate scenario. What are the precipitation patterns that go with unusually warm arctic seasons or years? There have been three studies of this. One has already been mentioned, the work of the University of East Anglia by Tom Wigley and his colleagues. Jill Williams (under her previous name) published a study of this, and more recently in Climatic Change Jill Yeager and I have published a review of precipitation distribution during anomolously warm Arctic periods.

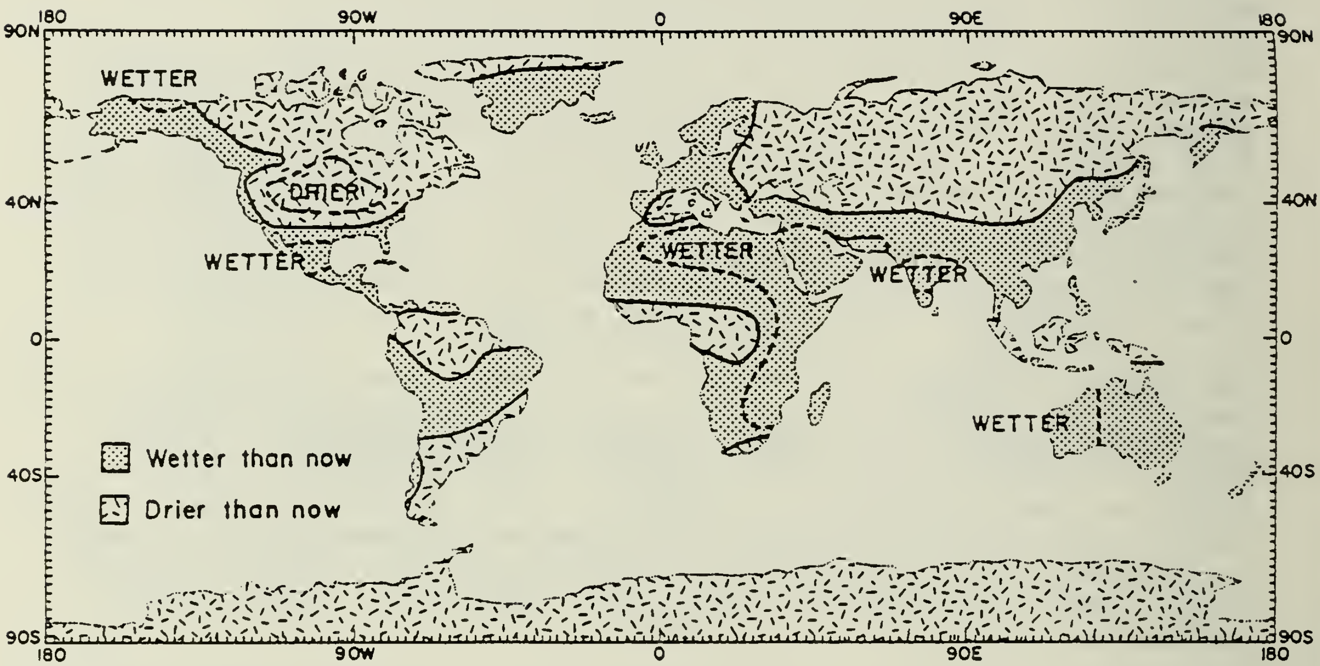


Figure 6

A climate scenario for the world, showing where it may become wetter or drier as the earth grows warmer. See text for an explanation of its basis. (Source: Kellogg and Schware, 1981; 1982).

I'm not going to show all these results because there isn't time, but on Figure 6 I have drawn a dashed line around the areas where we get agreement between all three kinds of information - the models, the Altithermal Period, and the anomolous patterns during the more recent period. For instance, they all seem to agree that the mid-continents at temperate latitudes (which includes the midwestern U.S.) are going to get dryer. In parts of the subtropics, which are now relatively arid, there should be an increase in the rainfall and soil moisture. This is a controversial map, because it is based on pretty uncertain inputs, but nevertheless it is intended to show what could happen. I am convinced that it has been useful, because it makes us think about the next question: What can we say about climate change in human terms? Can we interpret what a climate scenario like this means to us?

For the moment let's assume that this scenario shown in Figure 6 is going to be a good prediction. Can we interpret it in terms of agricultural production? For example, let's take corn or maize. Figure 7 shows 1978 world production of corn by country. The U.S. produced 49.5 percent of the world production, China 9 percent, followed by Brazil, and so forth. Most of the U.S. Corn Belt is due to become dryer, according to that climate scenario. Now consider barley: the Soviet Union produces 31 percent, China 10 percent. The barley-growing part of the Soviet Union is due to become dryer, according to the climate scenario. Wheat is shown in Figure 8: the Wheat Belts of both the Soviet Union and the United States are due to become dryer. Rice is mostly grown in China and India, where there may be, if anything, more rainfall, and furthermore as we get a warming they might be able to double crop or triple crop, so that there may be some hope that rice production would be even larger under the new condition.

The above discussion is intended to be merely suggestive but it's the kind of question that we ought to start asking. How will a given climate scenario affect agricultural production? Agricultural experts, many of whom are in this room, have been talking about this. The American Association for the Advancement of Science in 1980 came up with a study sponsored by the Department of Energy, and one of the panels was chaired by Professor Sylvan Wittwer, who is one of the speakers tomorrow. The study attempted to come up with some kind of an answer to the same kind of question: How will a climate change affect U.S. agricultural production?

A summary of this discussion was published in 1980 by Sylvan Wittwer in the Journal of Soil Conservation, and he said at one point that you could find various kinds of trees and other plants that grow in all 50 states and that sunflowers and soybeans can be grown anywhere from Texas to Minnesota. His conclusion: "Making the Minnesota climate that of Texas, therefore, would not eliminate many important crops." A few months after that learned scientific article appeared the New Yorker carried this cartoon (see Figure 9). It is not exactly what we would expect, but it is a dramatic illustration of some of the surprises in store for us.

I think I ought to emphasize once again the uncertainties in any discussion of the future. We can only make a rough estimate of what we're going to do

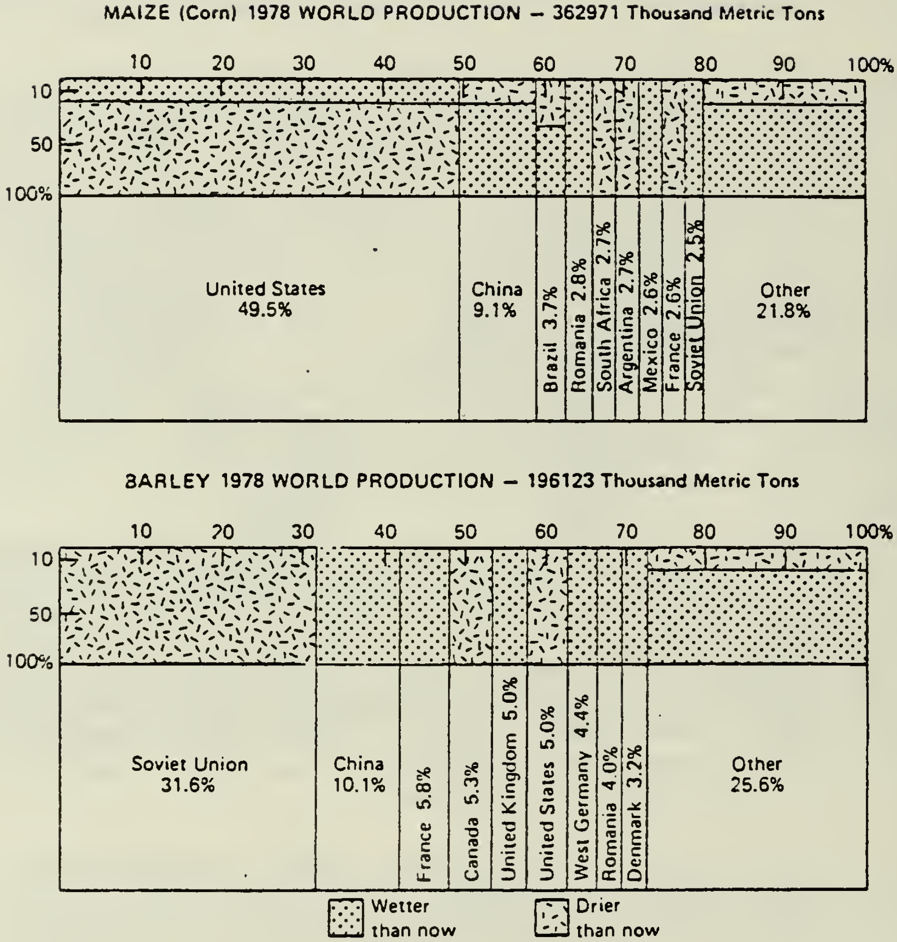


Figure 7

The 1978 FAO estimates of maize (corn) and barley production by country, and the corresponding trends in each country toward warmer or drier conditions in the future if the climate scenario shown in Figure 6 turns out to be correct. For example, most (but not quite all) of the areas of the United States that produce corn are due to become drier. (Source: Kellogg and Schware, 1981).

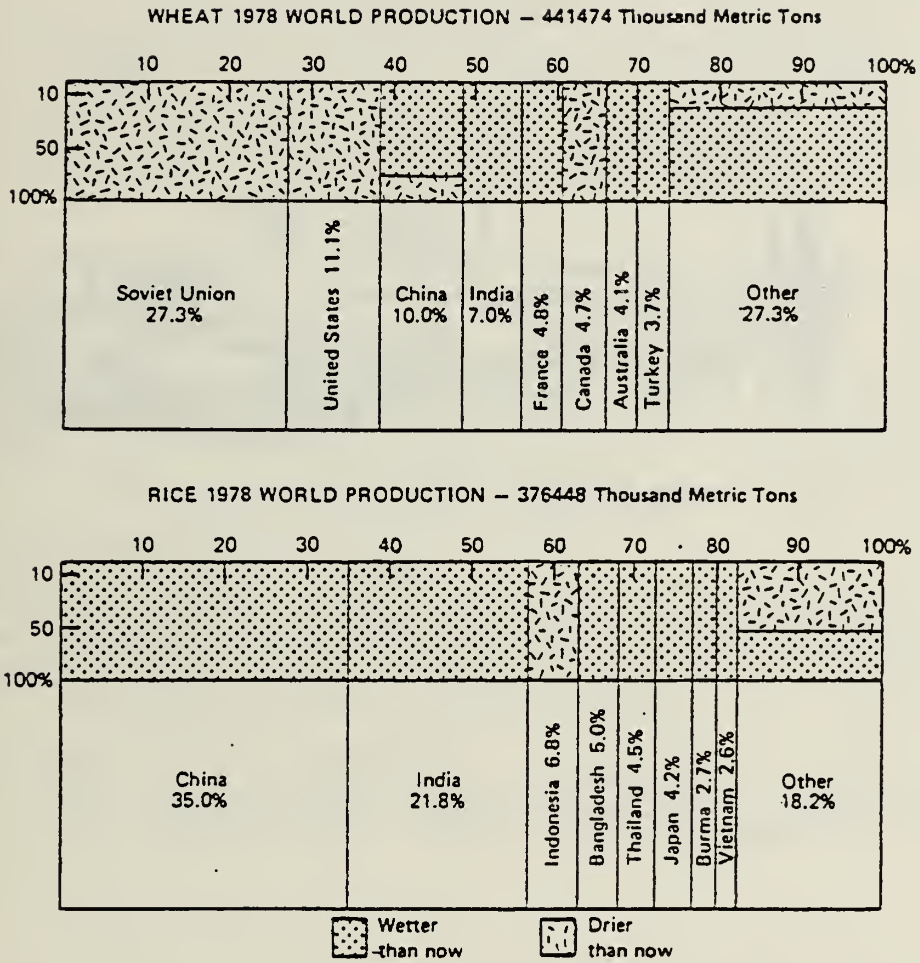
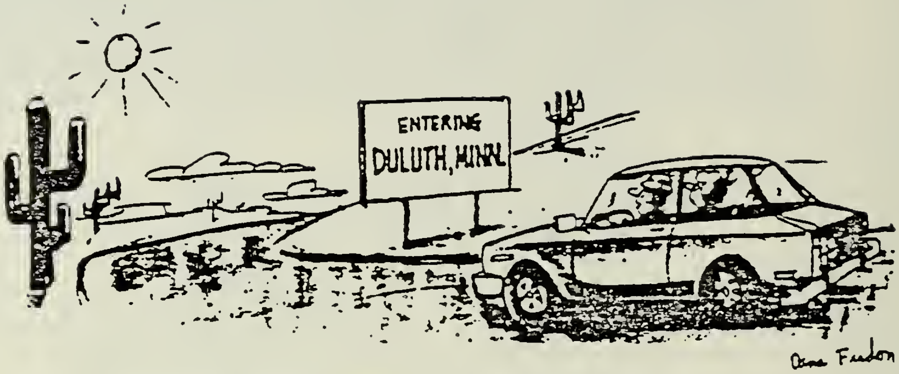


Figure 8

Same as Figure 7, but for wheat and rice.



"When things go wrong in this country, they really go wrong."

Drawing by Dana Fradon; © 1980 New Yorker Magazine

Figure 9

A humorous view of future climate change.

about fossil fuel burning. There are also some lingering uncertainties about our theory of climate and about our knowledge of the many things that influence climate. A Japanese geophysicist in Hamburg last month gave a brilliant All-Union talk to the International Union of Geodesy and Geophysics (IUGG), and he said: "Some of the things that I'm going to say are questionable. In Japan when we are skeptical about something we have a gesture that is this - we wet our finger and rub our eyebrow." We should all do that from time to time.

What conclusions can we draw from all this? I have a few suggestions, and one is that we learn to describe the future climate change in more regional detail and with a good deal more credibility than I have been able to describe it in my climate scenario (see Figure 6). And we should take into account other factors which I have not been able to take into account. For example, the extremes of climate and of weather are very important. When we talk about averages we're really talking about an unimportant aspect of climate as seen as by the farmer. The farmer and the rancher are concerned with getting through the extremes, so we need to know much more about the variability, and I have said nothing about future variability.

If we assume that this warming is going to take place and that we'll have changes in the precipitation patterns, something like the scenario that I've drawn: what should we do about it? Well, there are a number of things you can think of, and they're pretty obvious. There are such things as diversified agriculture, so that farmers have crops available to take advantage of the change in climate rather than being hurt by it. You can improve water management, and this is an obviously good thing to do - if you're going to have more rainfall or less rainfall, good water management can help you through.

Another thing is, of course, to keep the public informed about what the climatologists are thinking, so that they can be in on the decision process. This is something we're going to be talking about a good deal more later on, because people everywhere are going to have to respond if this climate change does occur. This meeting is a step in that direction.

These are all pretty obvious things to do. Furthermore, they're good things to do even if there were no prospect of climate change, as I think you will all agree.

REFERENCES

Clark, W.C., ed., 1982. Carbon Dioxide Review: 1982, Oxford University Press, New York (publication of the Inst. for Energy Analysis, Oak Ridge, Tennessee). 469 pp.

Flohn, H., 1979. A scenario of possible future climates--natural and man-made, chapt. IN Proc. of the World Climate Conference, WMO No. 537, World Meteorological Organization, Geneva, Switzerland, pp. 243-266.

Gilliland, R., 1982. Solar, volcanic, and CO_2 forcing of recent climatic changes, Climatic Change, 4: 111-132.

Hansen, J., D. Johnson, A. Lacis, S. Lebedeff, P. Lee, D. Rind, and G. Russell, 1981. Climate impact of increasing atmospheric carbon dioxide, Science, 213: 957-966.

Jaeger, J., and W.W. Kellogg, 1983. Anomalies in temperature and rainfall during warm Artic seasons, Climatic Change, 5: 39-60.

Keeling, C.D., 1982. The global carbon cycle: What we know and could know from atmospheric, biospheric, and oceanic observations, prepared for CO_2 Research Conference: Carbon Dioxide, Science, and Consensus (September, 1982), Coolfont, West Virginia, sponsored by the U.S. Dept. of Energy.

Kellogg, W.W., 1982. Precipitation trends on a warmer earth, chapt. IN Interpretation of Climate and Photochemical Models, Ozone, and Temperature Measurements, ed. by R.A. Reck and J.R. Hummel, American Inst. of Physics, New York, pp. 35-46.

Kellogg, W.W., 1983. Impacts of CO_2-induced climate change, chapt. Carbon Dioxide: Current Views and Developments in Energy/Climate Research, ed. by W. Bach, A.J. Crane, A.L. Berger, and A. Longhetto, D. Reidel Publ. Co., Dordrecht, Holland, pp. 379-413 .

Kellogg, W.W., and R. Schware, 1981. Climate Change and Society: Consequences of Increasing Atmospheric Carbon Dioxide, Westview Press, Boulder, Colorado. 178 pp.

Kellogg, W.W., and R. Schware, 1982. Society, science, and climate change, Foreign Affairs, 60: 1076-1109.

Laurmann, J.A., and J.R. Spreiter, 1983. The effects of carbon cycle model error in calculating future atmospheric carbon dioxide levels, Climatic Change, 5: 145-181.

Manabe, S., 1983. Carbon dioxide and climate change, Advances in Geophysics, Vol. 25: 39-82.

Manabe, S., R.T. Wetherald, and R.J. Stouffer, 1981. Summer dryness due to an increase of atmospheric CO_2 concentration, Climatic Change, 3: 347-386.

NAS, 1983. Changing Climate: Report of the Carbon Dioxide Assessment Committee, Natl. Academy of Sciences, Washington, D.C., 496 pp.

Rosenberg, N.J., 1981. The increasing CO_2 concentration in the atmosphere and its implication on agricultural productivity: I. Effects on photosynthesis, transpiration, and water use efficiency, Climatic Change, 3: 265-280.

Rotty, R.M., 1983. Distribution of and changes in industrial carbon dioxide production, J. Geophys. Res., 88: 1301-1308.

Wittwer, S.H., 1980. Carbon dioxide and climatic change: An agricultural perspective, J. Soil and Water Conservation, 35: 116-120.

WMO, 1982. Rept. of the JCS/CAS Meeting of Experts on Detection of Possible Climate Change (Moscow, October 1982), ed. by W.W. Kellogg and R.D. Bojkov, World Meteorological Organization Rept. WCP-29, Geneva, Switzerland, 43 pp.

IMPACTS OF CLIMATE VARIATIONS ON PRIVATE AND PUBLIC DECISION MAKERS

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The topic that we agreed that I would talk about really has to do with climate and human affairs, but we'll start out with something that doesn't appear to have anything to do with climate, at least until we look at it. Figure 1 gives a long record of the death rate in terms of infant mortality due to bronchial diseases in Tokyo. Why would we start a climate talk with that? Let's ignore the trend for a minute, and notice that there's a very, very large seasonal cycle. If you take a look at that you'll notice that the death rate increases markedly in the winter relative to the summer. All of us who live in seasonal climates know that's the flu season. When you're dealing with climate and human affairs, if you do what Wayne Wendlend referred to earlier as "fitting regression lines between two events which occur," you often draw conclusions which can be dangerous. Here, though, it's certainly not dangerous to draw the conclusion that there is an association between the seasonal cycle and pneumonia death.

On the other hand, how do you explain the downward trend? Well, I'm sure that any climatic determinists in the group, or the ghost of Ellsworth Huntington, would try to find some climatic way to explain it. In reality, of course, what we're really seeing in terms of the diminishing death rate trend is not a dramatic improvement in the wintertime climate in Tokyo, but simply the postwar economic recovery, the improvement of sanitation and better health services.

Whenever we're talking about climate and human affairs, not only do we have the risks Wayne referred to in making a false association between two lines that either go together or against each other in the physical realm, but we also have the same problem when trying to associate events for people with events in nature.

Climate can be viewed in three basic perceptions that are not independent. The first one that comes into mind, particularly for the food growers and for individuals, is <u>climate as a hazard</u>. Figure 2 is an example of the Palmer Drought Index as of June 27, 1981, and you can see there were some periods, such as in the north-central states, where there was extreme drought. Water supplies were doing pretty well right around Champaign on that date. What is unusual was that the northeast and middle Atlantic states, especially the middle Atlantic and the northern and southern states, were having strong drought periods. They were in fact having water shortages then.

There are two things to be learned. Number one is that extreme patterns can be found anywhere, and number two is that there can be compensations from place to place. One of the problems that cropped up in the Northeast was, simply, how do you get water from the areas where there are excesses to other

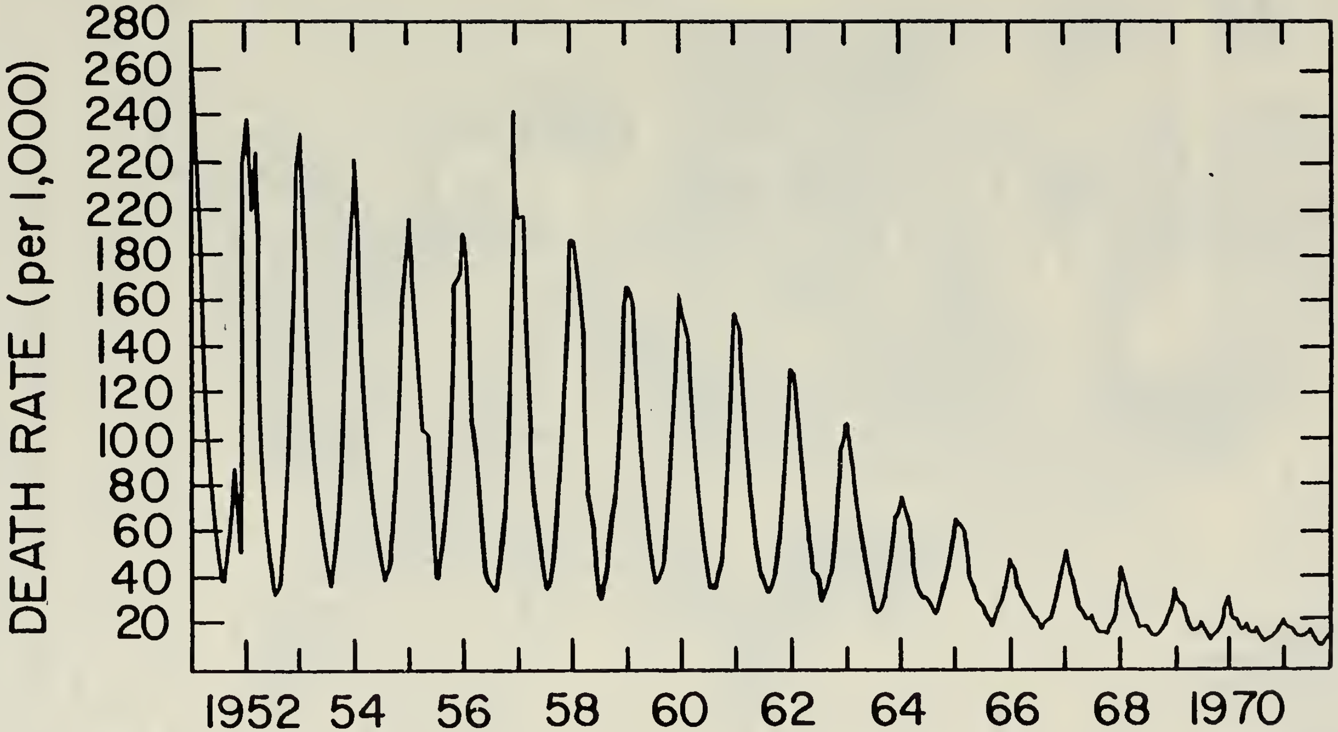


Figure 1. Trends in infant mortality from respiratory causes in Tokyo. (Source: Moniyama, M., 1975, Seasonal variation of mortality with special references to thermal living condtions. In Physiological Adaptability and Nutritional Status of the Japanese, Human Adapabilility 3, Yoshimura, H. and Kobayashi, S. (eds.), University of Tokyo Press: Tokyo, 136-147.)

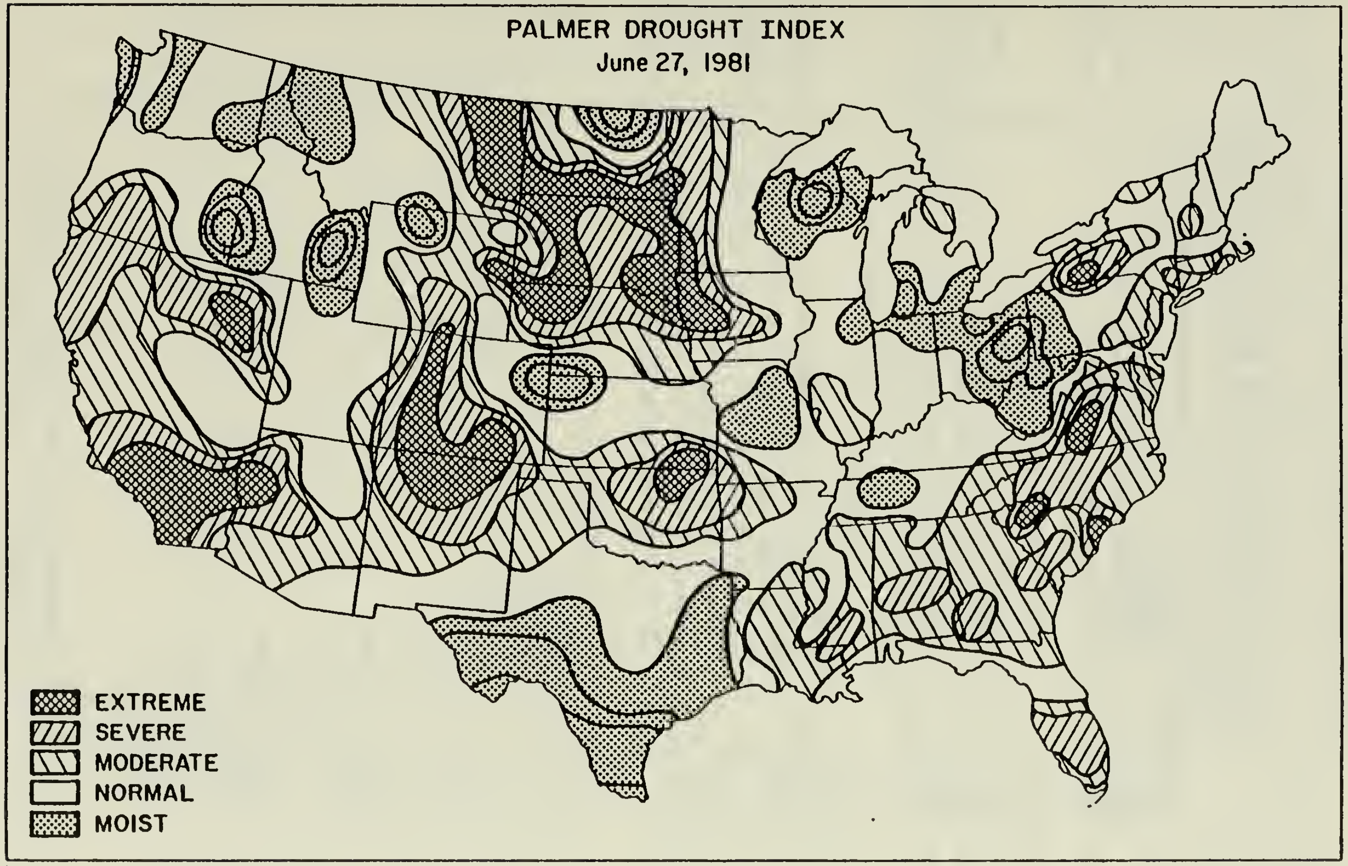


Figure 2. Variations in Palmer Drought Index over the U.S. on June 27, 1981, showing high degree of spatial variability of short-term climatic events. (Source: National Oceanic and Atmospheric Adminstration.)

areas, sometimes just 100 miles away, where there are deficits? This is something which is very hard for an individual local decision maker to do anything about. That has to be dealt with at a more collective level through larger-scale planning - and often not through market mechanisms. When the climate fluctuates either in space or in time, it impacts different economic units at different levels of aggregation - state level, regional level or local - and one has to be very careful to keep that regional scale of climatic anomalies in mind whenever one makes any statements about interactions between climate and society.

Another way to view the climate-as-a-hazard concept is to look at climate as not just varying in space, but also as varying in time. Figure 3 is a picture of corn yield in Missouri through about 1973, and you can see the drought effects. This is another climate-as-hazard issue. You'll also notice the large deviations from the average yield in the '30s and in the '50s, then this tremendous increase in yield which we all know is due to technological factors, in particular the development of crop strains that could take advantage of the fertilization that now takes place. There was a large debate as to whether the diminished variance, that is the individual dots or the individual yearly yields, was due to a good trend in the weather or due to technology. That debate still goes on. This type of graph caused a rather nasty debate between several agronomists, mostly around Columbia, Missouri - Jim McQuigg, Louis Thompson and others - and the then-leadership in the USDA as to whether it was necessary to have grain reserves or strategies to deal with the potential yield impacts of fluctuating climate. That's when the debate began to heat up about whether that nice, happy period of high yield growth and low yield variability would continue. Fertilizer usage can easily explain the trend on Figure 3, but can't, I believe, explain the variations year-to-year in yields after 1958.

On the other hand, after 1973, you may remember, there were several bad years. There was 1974 and there was 1980 and, of course, 1983. Although the corn yields in 1974, for example, were reduced by tens of bushels per acre, that was on a base yield level of 80 to 100 bushels per acre. The '30s saw (on Figure 3, for example) reduced yields by 10 or 20 bushels per acre, but that was on a base of 30. Therefore it seemed that the percentage of yield which varies interannually had been improved. That is, the relative fraction of the average yield fluctuating from year to year divided by average yield has been reduced. This so called "coefficient of variation" went down - even if absolute amounts of yield variations from year to year have increased.

Then Richard Warrick and several other geographers at Clark University came along and asked: "But is it fair to conclude that in the recent few decades, even in the bad years in the middle of the 1970s, that it was our technology that had reduced this vulnerability of crop yields to climate fluctuation?" Basically, what the Clark group asked was: "Was the climate fluctation in the 1970s as severe as it was earlier?" They compiled an area index of the number of divisions in the Great Plains which had a "severe" Palmer Index of less than -3 for years through 1977; it doesn't include 1980 or this year. If you take a look (see Figure 4), you see that in the mid-'70s, when there were corn or wheat yield reductions associated with that bad weather, the

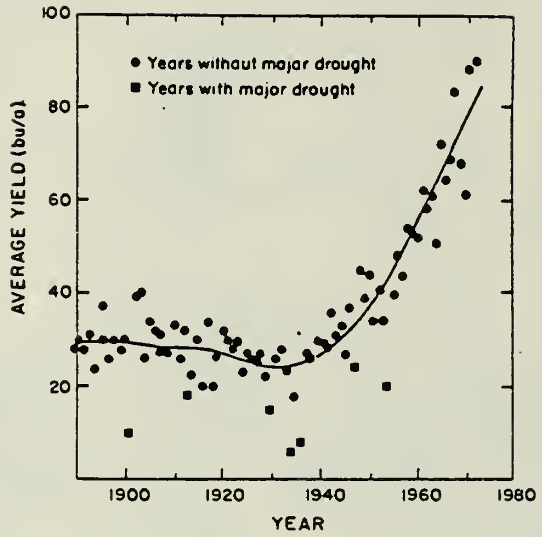


Figure 3. Corn yields in Missouri from 1900-1973. Individual yields for each year can be seen as dots or squares scattered about the trend line. (Source: Decker. W., The climatic impact of variability in world food production, prepared for the 1973 Annual Meeting of the American Association for the Advancement of Science, San Francisco, reprinted in American Biology Teacher, 36:534-540, December 1974).

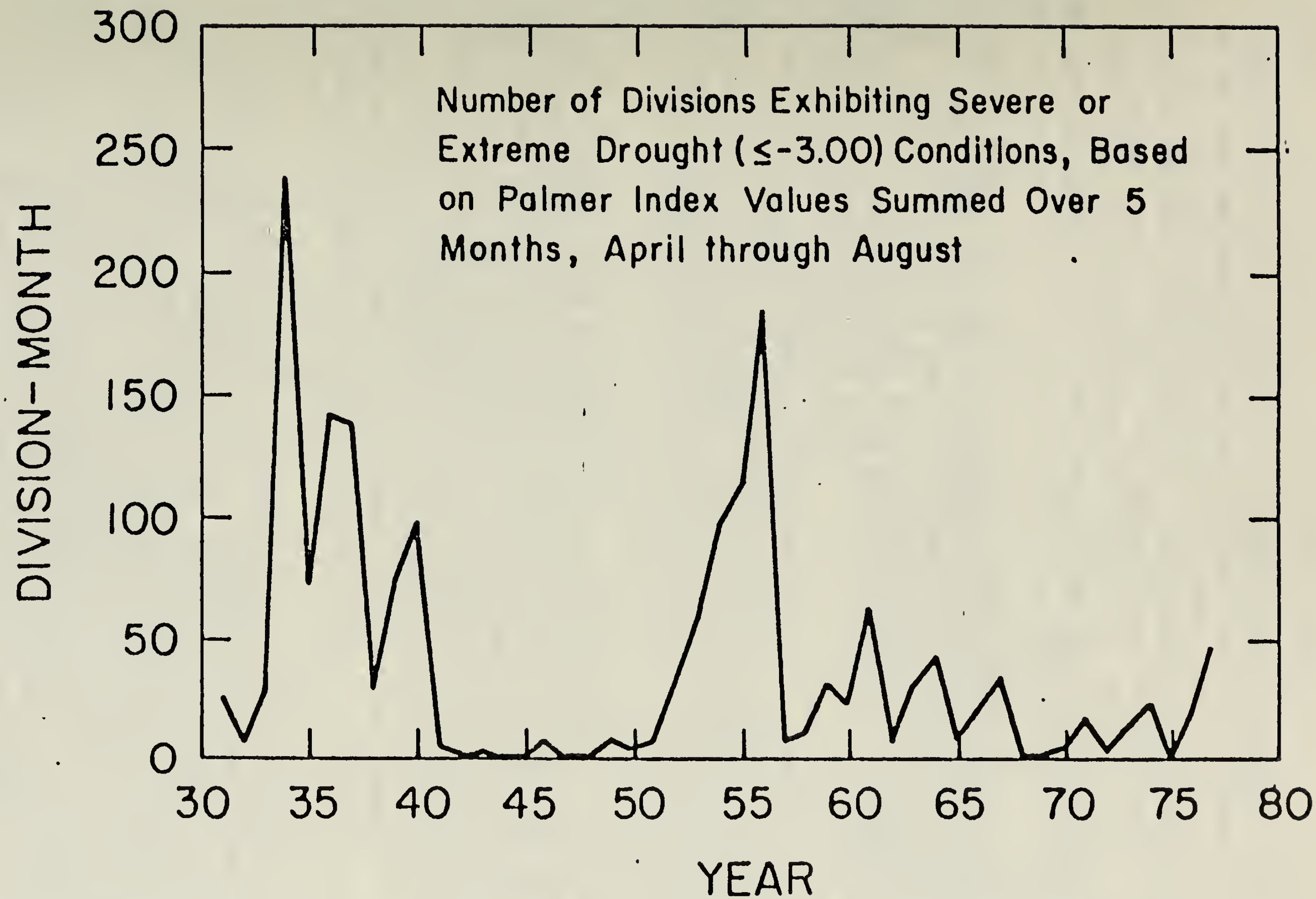


Figure 4. U.S. Great Plains drought area, 1931-1977. This figure is based on the work of Richard Warrick and his colleagues at Clark University, who divided the U.S. Great Plains into 64 climatic divisions and analyzed the number of divisions exhibiting severe or extreme drought for five months (April through August) of each year. Their measure of drought is the Palmer Drought Index, which suggests extreme or severe drought for values lower than -3. The units of the graph are division-months, that is, the number of divisions and months of each year in which the Palmer Index was less than -3. Note the extreme intensity and widespread nature of the droughts of the 1930s and, to a lesser extent, 1950s, but the relatively mild droughtiness in the Great Plains in the summers of the 1970s. (Source: R.A. Warrick, 1980, Drought in the Great Plains: A case study of research on climate and society in the U.S.A. In Climatic Constraints and Human Activities, Ausubel, J. and Biswas, A.K. (eds.), Pergamon Press: Oxford, 93-123.

area average Palmer Index was nowhere near as severe as it was in the '50s and the '30s. In essence, the fact that in the last 25 years we have had a seeming reduction in this coefficient of variation did not mean that the technology had reduced our vulnerability. It simply meant that the weather hadn't put technology to a stringent enough test. That's why, from a climatologist's point of view, it will be interesting this year to find out what happened to yields since the weather, at least in Illinois, has been as bad as it was in the '50s and '30s.

What causes yields to vary from average values? If you take a look at the monthly mean temperature and then try to figure out what the departure of yield will be if the temperature changes, you'll see that corn in Iowa, for example, is optimum for the normal temperature in June, but by the time you get to July and August it's actually too hot for optimum yields in an average year. They are growing corn in Iowa for economic reasons rather than because it perfectly matches the average climate. You can certainly tolerate being on the cool side. In fact, as Stan Changnon has shown, when you have runs that are cool and wet, your corn yields are more likely to be higher than "average." But you can't tolerate very much stress on the heat side and this again is part of this question of climate as a hazard. If you're going to get summer temperature fluctuations on the hot side, they're most likely going to be negative for corn in the Corn Belt.

Some recent work that I've done with two colleagues at NCAR looked at the issue of extreme temperatures. Temperature alone is important to corn, as most of you know, particularly in the month of July. That's the season when pollination occurs; so even if you have soil moisture in the fields, if you get over about 95°F (and they tell me over 100°F is much worse), you start reducing significantly the yield regardless of soil moisture. If soil moisture is depleted then it gets even worse. So we decided to take a look at the issue of the mean maximum daily temperatures: what are the probabilities of getting runs of five or more days in a row of temperatures above 95°F in July.

Consider Des Moines, for example. The mean max July temperature is 86°F, with a standard deviation of 6.8 degrees. Let's look at Table 1. "P1S" is the probability of having one single day above 95 degrees in the month of July at Des Moines. All of you would have guessed it was 11 percent, right? "P5S" is the probability of getting five days randomly chosen throughout the month of July, and it's 28 percent. That makes some sense because it's 11 percent on one day; and you've got 30 days in a month. It should be a higher number than 11 percent. It's almost a 30 percent chance that you're going to have five 95 degree days sometime in July. But more importantly, I am told by agronomists, is whether you're going to get a run of above-95-degree weather in the tassel season. And that's this probability of P5RS. Today, that probability is around 6 percent in Des Moines. We've been talking about climatic hazards and there's a hazard of getting significant yield reduction which is about 1 chance in 17 of having a (P5RS) bad year in that part of the world. It's not all that different here in Illinois.

Table 1. Probalities of various extreme temperature events (see text).

	P1S	P5S	P5RS
Present	0.11	0.28	0.06
Present +3°F	0.22	0.71	0.21

We are now getting ready to talk about the second way we look at climate effects on society. First, as I said, you look at it as a hazard. The second way you could look at it is as an evolving trend. Suppose there is, as Will Kellogg and others have argued, an evolving trend. In fact, it's clear that there has been on the order of a half-a-degree Celcius (or a bit less than a 1°F) global warming over the time scale of the past 100 years. Suppose this continues due to CO_2 or whatever and it increases the temperature by 3°F. Let's also assume that there is no change in climate variance with this warming trend.

Let's take a look at the second row on Table 1: "present + 3" tells us that if you increase the temperature by 3°F and you don't change the pattern of daily variance, the probability of having an above-95-degree day at Des Moines has gone from 0.111 to 0.222; so it's now a 22 percent chance. You have a 71 percent chance of five random days in July being above 95 degrees and you've gone from a 6 percent to a 21 percent chance of having runs of five consecutive above 95°F days. Now, although you might think that a change in the mean of a few degrees may not seem that serious, what you're saying to a farmer or someone who has to invest in agriculture is that you've got to take a much higher probability of bad years into account. If the "bad" years now typically occur 1 in 20 and they're going to move to 1 in 5, then the economics becomes different. That's why you hear people saying, "the Corn Belt moves north with a warming trend," because it would not be nearly as safe to grow corn if you have those kind of risks of hot weather.

Of course, reality may not have such a scenario of changing probability of extremes on Table 1 just because the mean temperature goes up. You can change the variance as well. You can also change the autocorrelation. I'm not arguing Table 1 is a reliable simulation of the future. But when you're going to be making private decisions and somebody tells you about a couple of degrees' change in temperature, you have to look at more than just the average effect on individuals. We have to look at what this sort of change; implies for variability, and what that might mean for the well-being of the region - or the nation. If you want to get attention in Washington, you don't just show extremes in the Corn Belt, you do it for Washington, D.C. The probability of runs above 95°F are 17 percent in Washington right now; and if you add a trend of 3°F, it goes up to 47 percent. If I brought this information in front of Congress and discussed it, I'm sure there would be someone there to say, "Well that's easy to solve. We humans are ingenious and resilient. We'll just cancel all the Congressional sessions in the summer."

There's a third way to view how climate affects human affairs. First, as a short-term hazard; second, we've said, is as an evolving trend; and then

third is as a resource. Figure 5 is an example of rainfall variability. The dark areas are where the fraction of rainfall from year to year is a very large fraction of the mean. The more such uncertainty in yearly precipitation reliability you have, the more shaky farming investments become because you have boom-and-bust years. You don't usually get much investment in those areas unless governments try to do as the Soviets did in the Krushchev era. This time frame represents an element of climatic resources. These too can change with trends, but one also has to view climate again in this third incarnation as a resource that one could exploit. Now if the climate changes and it changes rapidly, it is likely that it will not, on net balance, be very helpful because people won't adapt to it before being damaged. But this doesn't mean over time that it couldn't be helpful for climate resources to have a trend because you can adapt your practices to fit to the new climate if you have enough notice, and sometimes this can be a benefit.

There aren't just trends in climate, but there also are trends in human activities. Figure 6 gives total grain production. You'll notice that production goes up almost linearly during this 1961 to 1982 period - and I'm sorry I don't have 1983 on this graph, because if you look at the upper right it will be quite a bit down. Someone read a headline this morning saying that, thanks to the drought, production - not productivity, since production is the average amount of yields times total acreage - in corn and soybean production drop will be down something like 40 percent. They forgot to say that half of that production drop is because of the PIK program and only the other half is due to weather-decreases yield; so humans are once again in the act, mixed up with nature in making climatic impacts on society. Also on Figure 6 we can see a long run of rather negative yields between '74 and '78, which is in fact exactly what the agronomists at Columbia, Missouri were warning about 10 years ago; and the fact that it occurred right after their warning was lucky for them, but unlucky for the farmers.

Has the weather become more or less variable? Stan Changnon showed a graph on this this morning. The trouble with deciding whether variability increased or decreased is that it all depends upon how you define variability. Is it sequence of abnormal years, is it for temperature, or is it for rainfall? To me, the most important climate variability statistic for agriculture is simply how yield has changed, so let's not get into the argument of what the climate itself did. There are simply too many variables to choose from to have a meaningful statement for farmers. Let's just say that as integrated by all the grain crops of the world, the yield, which is the third graph down on Figure 7, was fairly steady from the 1960s right up through about 1972. The yearly yield deviation from the trend line was very small. Then, after that you see a much larger set of world yield fluctuations. Whether that means the "climate variability" increases is hard to say because different crops integrate different weather effects, but (at least in terms of average world yields and from what we've seen in the U.S. productivity statistics) it has.

What do you do about that? There is something that individuals can do. They can set up their own kind of reserves to deal with fluctuations. But the reserve that most of us set up as individuals is to support a society where

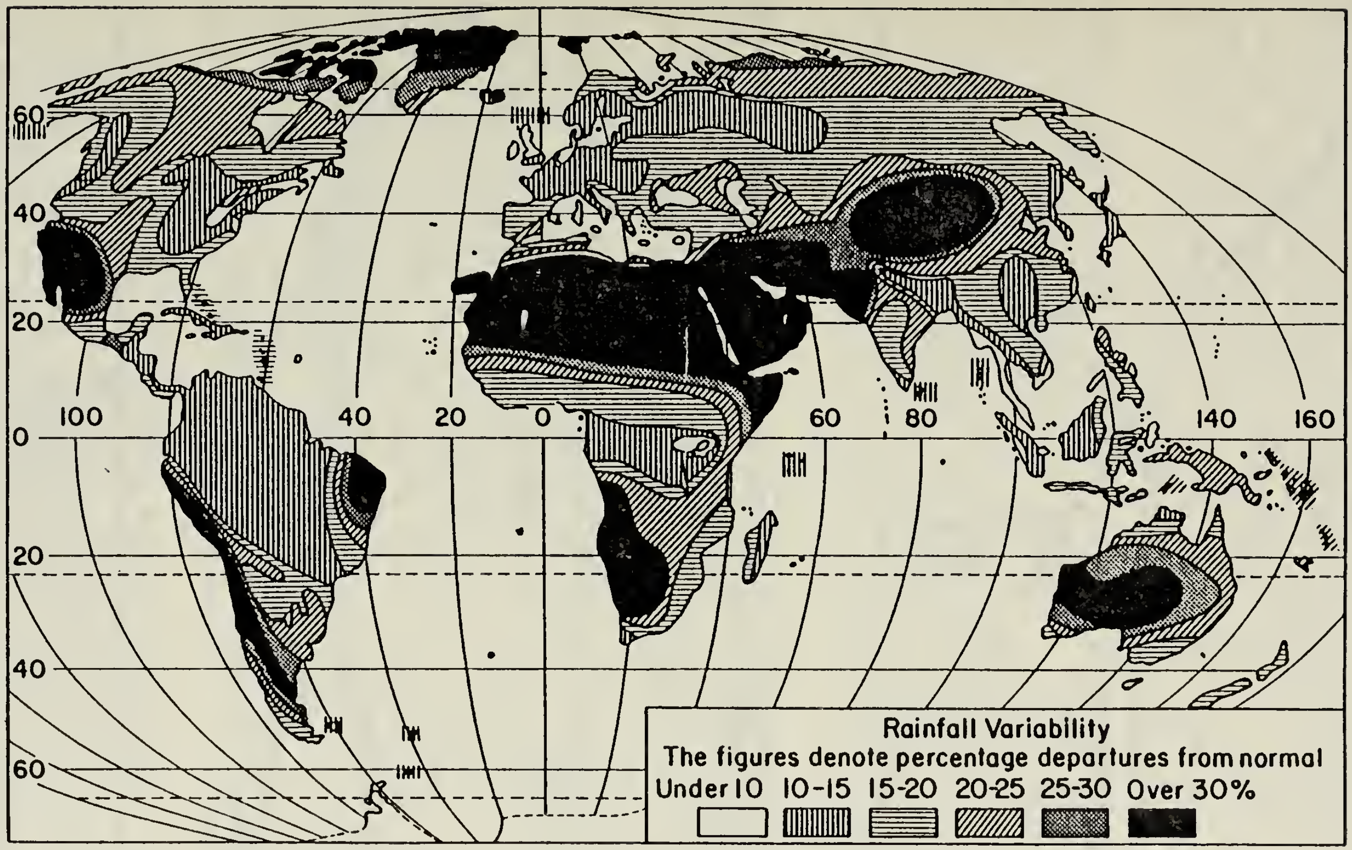


Figure 5. Annual rainfall divided by long-term average precipitation is one useful statistical measure of climatic variability. This rainfall variability measure tends to be highest in places where there is either very little annual average precipitation or where most of the annual rainfall occurs in a few storms or over a short season. (Source: Pettersson, S., 1969, Introduction to Meteorology, 3rd ed., McGraw-Hill: New York, 275.)

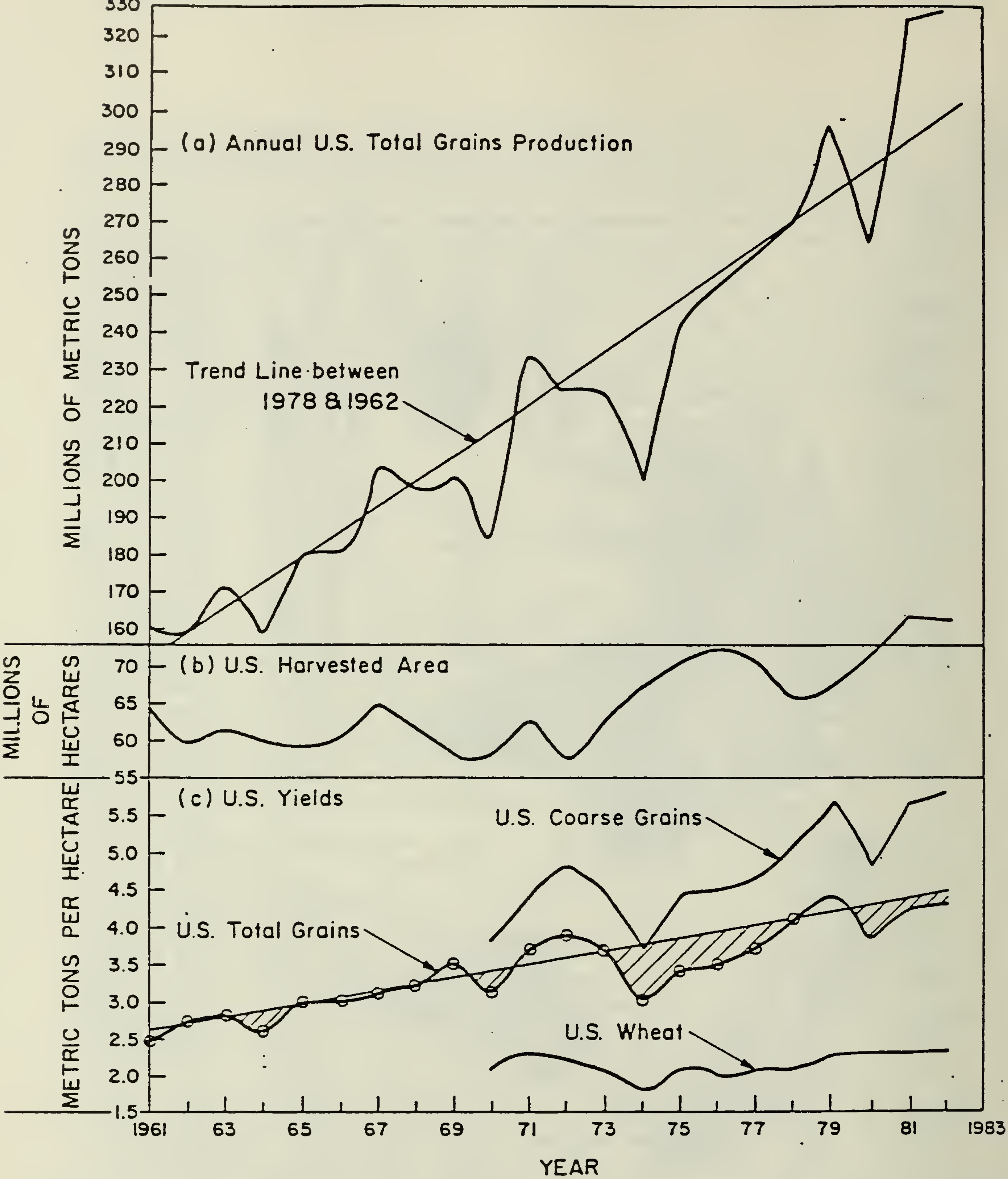


Figure 6. Grain production harvested area, and yields in the United States from 1961 through 1962. (Preliminary estimates suggest that U.S. production of coarse grains in 1983 will be nearly cut in half by a combination of summer heat and planted-area reductions encouraged by a government program.) Note that yields of total grains showed relatively little departure from the long-term trend line before 1973, but that the variability seemed to have increased after 1973. (Data from U.S. Department of Agriculture, World Grain Situation and Outlook: Foreign Agricultural Circular, Government Printing Office: Washington, D.C., FG-26-82, August 1982.)

we trust government or the corporations to somehow produce, collect and store enough food to give us what we need over time. We don't usually provide enough food for ourselves as individuals.

Another thing you can do as an individual or a corporation, if you're a grower, is to invest some of your economic return in a hedge against dry weather through irrigation capability. You can also use irrigation to extend your climatic resources, even in "normal" weather. You have lots of growing degree days and lots of sunshine in dry parts of the high plains where you don't typically have adequate moisture, and if you have groundwater you can pump. Of course, you pay a price, but you can do that.

On the other hand, you may be lulled into some false sense of security by irrigation capability because it isn't just the dryness that hurts crop yields, but also the high temperature itself. As we've discussed earlier, hot weather can affect yields if it comes at the wrong time. That's why it will be interesting to see what the differences in the 1983 corn yields were, say in Illinois, in the irrigated versus the unirrigated fields, to estimate the relative efforts of moisture or temperature stress. From such analyses you'll learn just how good your irrigation hedges are. These are examples of things that individuals can do and they're classic; they're obvious in a sense.

What is the government's role? The government can make it more or less easy to invest in irrigation through loan programs or through other measures. On the other hand, some argue strictly on the "free market" basis that individuals will have to find their own investment dollars. The problem is that although we have lots of technological ways to minimize our vulnerability to climate, they're not always so cheap - especially in the Third World. And again, although private decision makers may want to invest in them, you've got to have the money to invest. Then you have to be willing to take the risk of a couple of bad years coming along, in which your investment could be wiped out and you could end up losing your land. So people tend to be conservative and don't invest enough in protecting themselves against dry years. This is a role where I think the public sector has to come along. If it declares agriculture, for example, a national priority, then it has to be willing to help by helping people to make investments in agricultural infrastructure. Then, I believe, we need to make repayment terms on loans a little more flexible, perhaps with payments coupled to productivity rather than solely coupled to the time from when the loan was made. We need to be more creative in financing to encourage agricultural development.

Of course, you can always store things against bad weather, and we have seen great arguments about whether stored grain should be public or private, how much there should be, what its effect on prices is, etc. Figure 8 shows "world grain security," which is reserves worldwide divided by utilization. As you see around the beginning of the 1970s, about 15 percent of all the grain that was used was stored. This dropped to around 10 percent in the food crises in the early 1970s. Notice in curve b that the price of wheat and corn is very anticorrelated with grain security. Here I think that association is cause and effect.

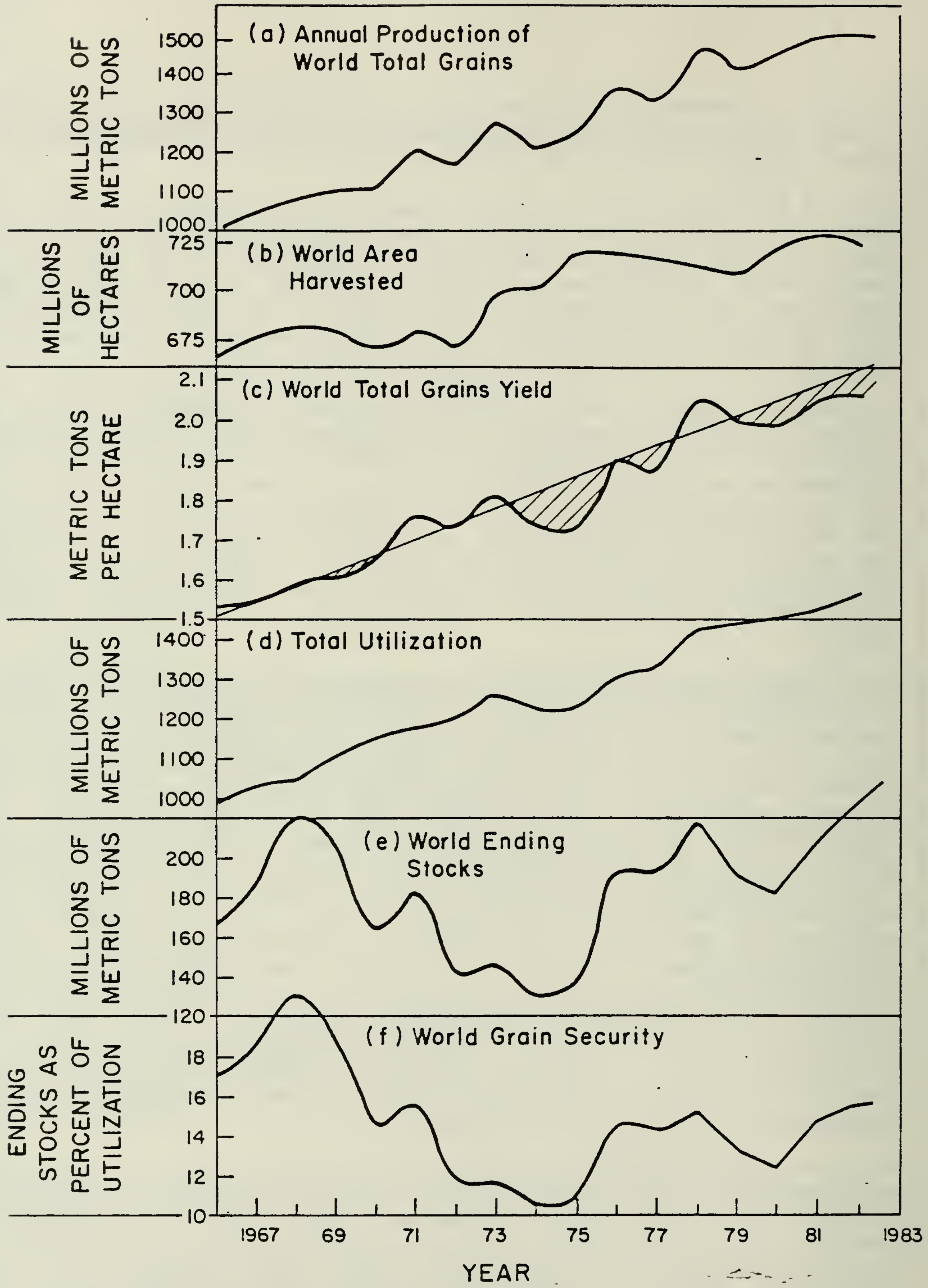


Figure 7. Data for production, harvested area, grain yields, utilization, ending stocks, and grain security for total world grain production between 1966 and 1982. Note the apparent increase in year-to-year variability of world total grain yields (part c) after 1972, in rough agreement with results for the United States seen earlier in Figure 6c. (Data from U.S. Department of Agriculture, World Grain Situation and Outlook: Foreign Agricultural Circular, Government Printing Office: Washington, D.C., FG-26-82, August 1982.)

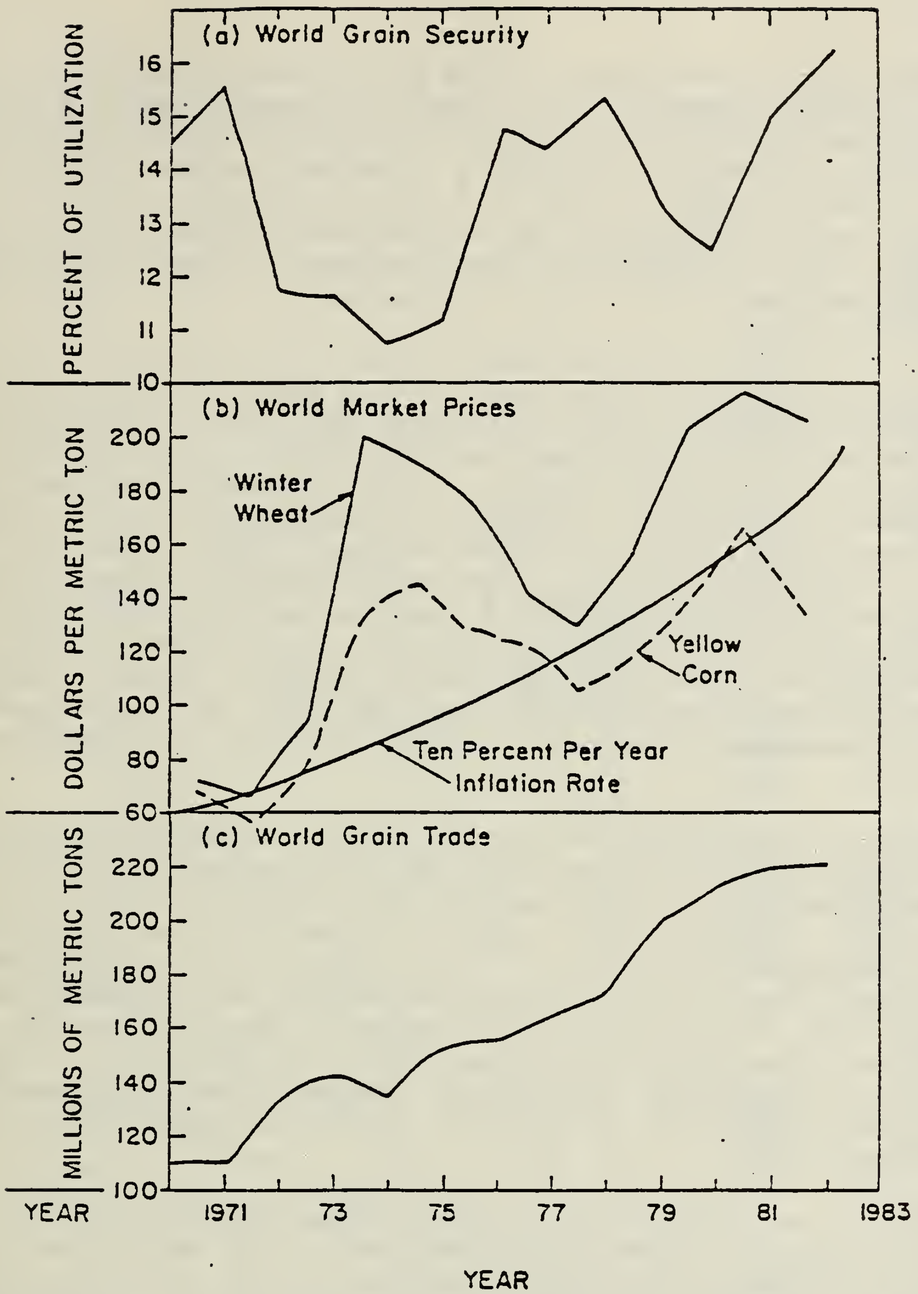


Figure 8.

World grain security, world market prices for winter wheat and yellow corn, and world grain trade, 1970-1982. Note the obvious inverse relationship between market prices and world grain security, reaffirming the classical market principle that increase in supply (relatively more grain storage) coincides with decreasing prices, and vice versa. However, the price trends do go up steadily over this period, and the 10 percent per year inflation rate curve in part (b) illustrates this inflationary effect. Note that with the exception of 1974, world grain trade increased steadily, showing no significant relationship with fluctuating world grain prices. This violation of classic economics doctrine for supply, price, and demand is probably rooted in the increasing demand for feed grains by affluent nations willing to pay virtually any price to maintain meat-eating habits. (Data from U.S. Department of Agriculture, World Grain Situation and Outlook: Foreign Agriculture Circular, Government Printing Office: Washington, D.C., FG-26-82, August 1982.)

What I found most interesting on Figure 8 is curve c: World Grain Trade. According to basic economic laws of supply and demand, when the price goes up people buy less. Well, take a look at that graph. There's no connection between price and imports, and there's no connection because most of the imports in the world are, in fact, U.S. grain and most of it is U.S. feed grain going not to the poor but to the rich who are feeding it to animals. Since their dietary standards are very important to them, they are quite willing to take factors of 2 and 3 fluctuation in price to maintain their standards of eating.

So we see once again that if you want to talk about the impact of climate on food systems, particularly the Third World, that trade is important and that price is not an obstacle for those who can afford to buy. When you argue about what is the best policy at what level, you have to talk about whose value systems are involved. Are you out to do the best for the producer, the best for the trader, the best for the consumer - the consumer here, or the consumer in India? You have a variety of conflicting interests to resolve, and these are typically dealt with at some sort of government level. (Another thing a government can do is have a research program to help us become less vulnerable to climate hazards, predict evolving trends or take better advantage of climatic resources.) There isn't very much you can do to influence the government's policies, from an individual point of view, except vote.

Just how much climate predictability is there? The Climate Analysis Center put together a study which shows what the climatic anomalies in the wintertime were in the U.S. following each of the previous, not this year's, major El Nino events. They could not identify a complete, clear and discernable statistically repeatable pattern. There is some set of associations, but mostly those El Ninos clearly cause major changes that are detectable nearby where they occur, but as you get further and further away from the equatorial Pacific Ocean into our latitudes, the strength of the signals starts to diminish relative to other influences. Nineteen eighty-three saw such a big El Nino event that perhaps we will soon be able to explain the year's many weather anomalies.

What things can we do to help us predict weather anomalies? We can also look at volcanic events. In 1982, El Chicon blew its top and sent up a large cloud of stratospheric dust. It probably cooled the mean global climate by a few tenths of a degree, but it will take more anlaysis to determine the eruption's <u>global</u> effects. Regional impacts may never be discernible.

The final issue, which you've heard a lot about this morning, is carbon dioxide. Figure 9 gives projected CO_2 growth scenarios ranging from some people's economic pipe dream of 4 percent per year growth to 1-2-3 percent growth rate down to constant emission. Notice constant emission still continues to cause CO_2 to increase. The reason for that is constant emission from humans is still a disequilibrium in the uptake of CO_2 in oceans and the biosphere, so it takes time before constant emission levels off. Amory Lovins' counter pipe dream of a negative energy growth scenario is also

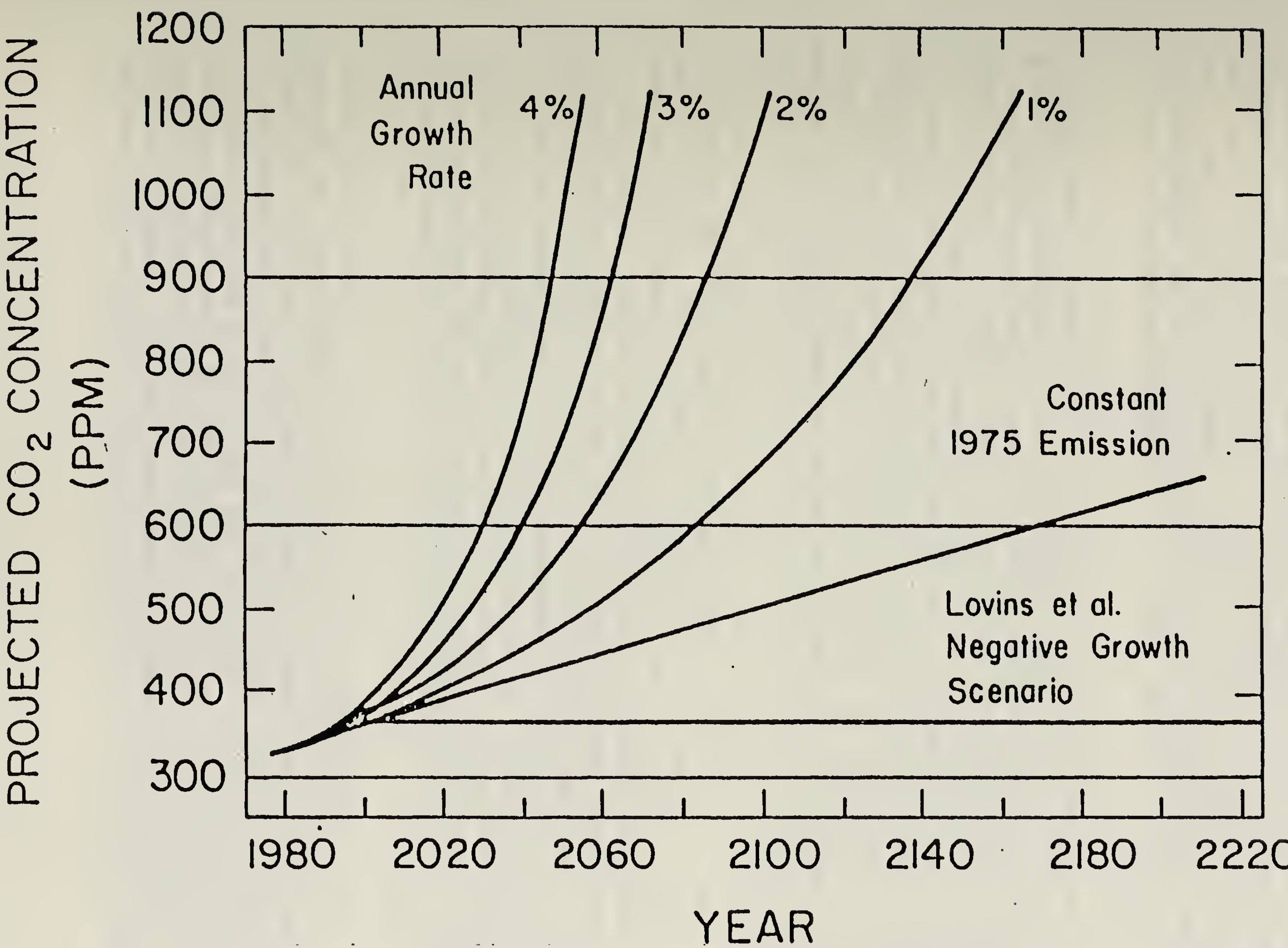


Figure 9. The extent to which CO_2-induced climatic change will prove significant in the future depends, of course, on the rate of injection of CO_2 into the atmosphere. This depends, in turn, on behavorial assumptions as to how much fossil fuel burning will take place. (This graph neglects biospheric effects.) Since the end of World War II, a world energy growth rate of about 5.3 percent occurred until the mid-1970s, the time of the OPEC price hikes. Rates have come down substantially since then. The figure shows projected CO_2 concentrations for different annual growth rates in fossil energy use, including the assumption that no increase in fossil energy use occurs (constant 1975 emission) and even a "negative growth scenario" in which energy growth after 1985 is assumed to be reduced by a fixed amount (0.2 terra watts (TW), which is about 1 percent of present demand) each year. (Source: A.B. Lovins, L.H. Lovins, F. Krause, and W. Bach, Least-Cost Energy: Solving the CO_2 Problem, by Brick House: Andover, 10.)

given. For most estimates, it's sometime between the middle of the next century to the one after that to get something on the order of a doubling of CO_2 after which we might shift to other energy sources. This implies a warming of several degrees, as shown by Will Kellogg.

The question for us is what can we do publicly or privately about this kind of an issue? First of all, do we believe it? It's one of these problems where you can't really show a direct effect until you've lived through it. And therefore you have to ask yourself the question, how can we find some surrogate to give us some hint that we're feeling the effect? That surrogate could be a model or that surrogate could be an advanced sign - the fashionable word now is a "CO_2 fingerprint." Even though the sign (e.g., the 100-year 0.5°C global warming trend) may be below statistical significance threshholds, we believe the CO_2 models a little more when nature is consistent with theory.

A very similar question involved in acid rain is: "Can we get reasonably definitive proof before the system itself performs the experiment with us as the living creatures in the laboratory?" My answer to that question is "probably not." Therefore, we have to ask how we can deal with this dilemma. If we're going to force ourselves to adopt to future CO_2 or acid rain increase and if we're going to insist on the strictest criteria of demonstrated detection before we take any social action, then we must also recognize that we're committing ourselves to a larger dose of whatever effects they may be, for better or for worse, than if we were to have taken action in advance. And research is, of course, one hedge because it speeds up the date at which we can have increasing confidence in what's going on, but it doesn't guarantee certainty.

What kind of empirical evidence for CO_2 warming can we show? We heard a lot about models. It's hard to verify what the models tell you about causes of the temperature changes over the last 100 years. And the simple reason for this is that although we know something about the number of volcanic eruptions, and we know something about the CO_2 emission, we just don't know to better than about the factor of 2 how those volcanic eruptions translate themselves into a radiation perturbation to the atmosphere. We have only known this since 1963. We do not know what's happened to the energy output from the sun except in the last five years. There are just too many other uncontrolled plausible external factors to have any statistical confidence at all in our cause and effect reconstructions for the temperature of the past 100 years.

Basically, if any of you are statisticians, you want to know how many independent degrees of freedom are in the data, and how many independent degrees of freedom you have in your model - "tunable knobs," if you will. Statistical significance is a meaningless concept until you can define the number of degrees of freedom you have. And since you can't easily do that without an argument over independence, the whole idea of finding statistically significant effects rests on the assumption of these numbers of independent degrees of freedom - which will be argued endlessly until you get a signal like Will Kellogg showed of a degree or two. Then everybody will believe it, and then

we'll have to adapt to it. So what you need to turn to for advance warning is surrogate verification of these models.

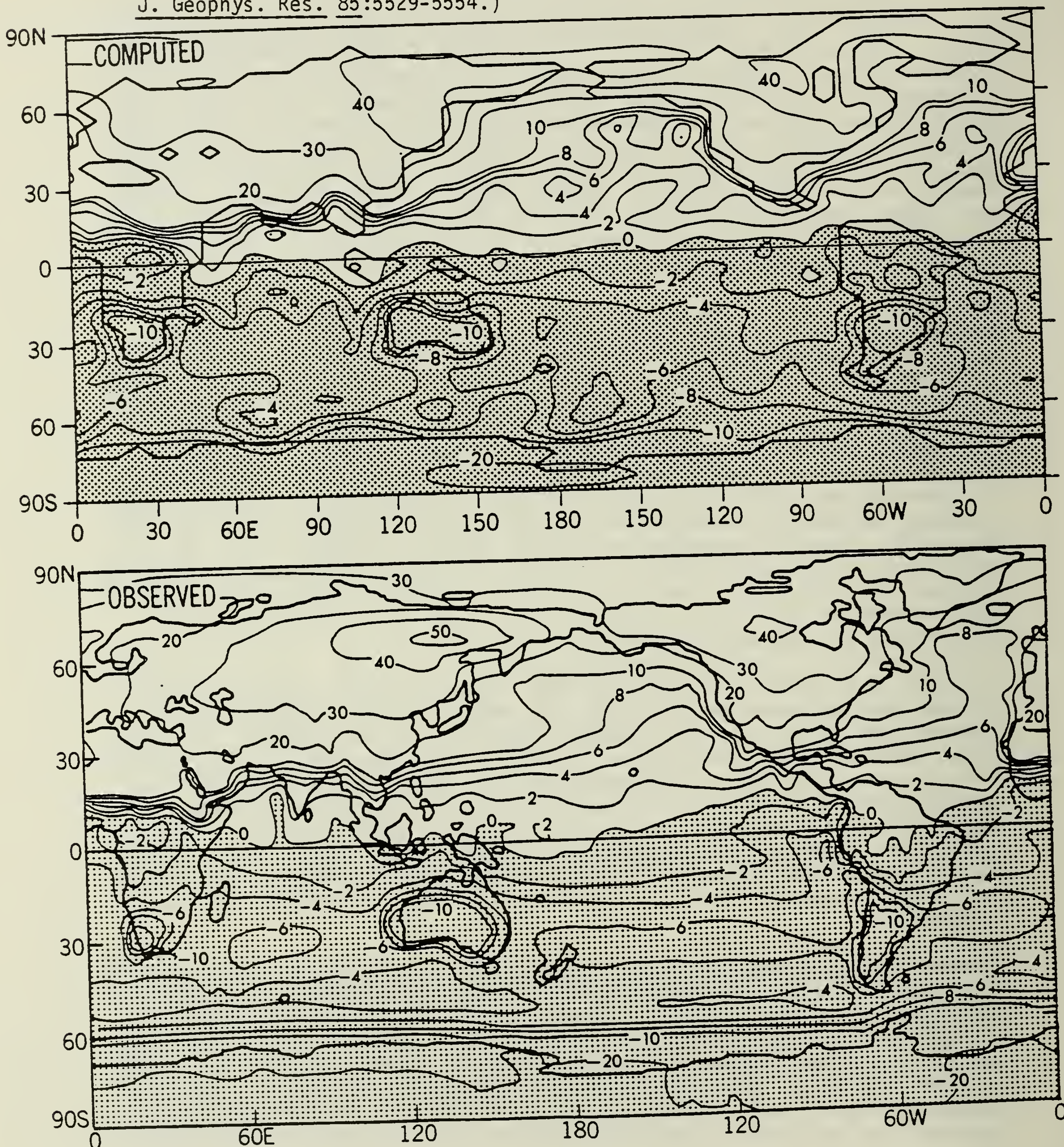
I just want to show Manabe and Stouffer's results, not on a CO_2 case, but on a surrogate experiment which, in fact, is the largest climate change that is predictable: it's the seasonal cycle. The range of the seasonal cycle in the Northern Hemisphere is about a 15°C difference between winter and summer. The difference between the last ice age and the present, we heard this morning, was around 5°C. So each season is roughly three times an ice age. Now it's not an equilibrium ice age. In fact it's not even clear that ice ages are in equilibrium. But this is another debate. Nevertheless, the seasons are a very large climate change. If there is some major cloud feedback going cloud feedback going on, or if there are other factors in the models that they are doing wrong, they're going to badly predict the seasonal cycle.

On Figure 10, you can see the temperature difference between winter and summer, the difference predicted in this case by the Manabe and Stouffer model and by observations. Despite some things that are wrong - not every place matches up perfectly - the general patterns are really remarkably good. I find it hard to believe that there are any short-term mechanisms, at least, that are so dominant and badly modeled that they're going to completely invalidate the predictions of the models. If there were such mistakes, present models simply could not get the seasonal cycle right. But CO_2 is a different forcing than the seasonal cycle. It operates on different time scales. The deep oceans don't participate in the seasons very much and they do in CO_2. So the CO_2 problem is not yet verified in models, although surrogates like the seasonal cycle do tell us that at least we have some good grounds for confidence in model predictions. Of course, if we don't want to believe them we can always gamble that the models have overestimated the CO_2 effects or that adaptation will be easy.

What can we do about something like CO_2? There are still things we can do even in the absence of certainty. We don't have to destroy the coal industry and we don't have to stop the Third World's development, which is partly tied to fossil fuel energy. What we have to do first is stop wasting. This is obvious. Simply, profligate waste of energy not only is expensive, but it also commits the future to a larger dose of whatever consequences CO_2 increase brings, better and worse, than if we are more prudent. If you're not a gambler you'd rather keep your potential impacts low. Therefore, conservation, end use efficiency or whatever you want to call it not only makes economic sense but can mitigate the CO_2 - and acid rain - problem.

You can also look for substitutes. Solar power, for example, is not going to "save the world" in the time scale of the next 10 or 20 years as some zealots claim, but it's a part of the solution. It can be 10 percent, and wind can be 10 percent, and conservation can be 25 percent, etc. All of a sudden you start adding these up and pretty soon, while you haven't eliminated the CO_2 problem, you've cut back its impact by a factor of 2 or more in the time scale of 50 years and you have done this without economic harm to yourself. In fact, you've probably done things cheaper. But you need a little help.

Figure 10. A three-dimensional climate model has been used to compute the winter to summer temperature extremes all over the globe. The model's performance can be verified against the observed data shown below. This verification exercise shows that the model quite impressively reproduces many of the features of the seasonal cycle. These seasonal temperature extremes are mostly larger than those occurring betwenn ice ages and interglacials or for any plausible future carbon dioxide change. (Source: Manabe, S. and Stouffer, R.J., 1980, Sensitivity of a global climate model to an increase of CO_2 concentration in the atmosphere, J. Geophys. Res. 85:5529-5554.)



If you leave it only to the "free market," such a solution is unlikely to be done rapidly simply because free market investments are based upon the short-term return on investment. If you are looking for high returns and there are high interest rates, then you really can't think long range. So here again, while a private decision maker can't do very much about CO_2, public decision makers can, and I mean public at national and international levels. They can agree to try to put a little bit of seed money into the development of energy supply alternatives and for more efficiency in energy end usage. But such vision isn't easy to implement. In fact, a former President spoke at a podium in Colorado dedicating the Solar Energy Research Institute's planned building on a mesa which right now is still home to rattlesnakes.

Finally, you can invest public money (and I think society should invest in such hedges) to make us less vulnerable to climatic variation or change. If you've got more seed stocks and you understand how each variety works, you can select strains that will be less vulnerable to whatever climate we have - but only if you've developed it and tested it. That's part of proper strategic investment strategies for the use of public money to hedge against climatic anomalies or trends.

Here is a photo (not shown) of an obvious non-farmer: Norm Rosenberg. As many of you know, he is an agrimeteorological researcher at the University of Nebraska; he's standing in a field of soybeans. I was wondering what the yellow flag was next to his feet and Norm showed me. If you look down very carefully between the soybeans, you can see a model railroad! What he's really got there is a photometer, which is measuring sunlight. He's running it on a track that's 10 feet long, back and forth on a bumper train, and he's measuring how much sunlight gets to the ground. What he's trying to do is help the plant breeders design soybeans so that very little solar energy gets to the ground so that more photosynthesis can take place in the leaves rather than wasting energy getting to the soil, merely heating it up. This kind of research is partially a government hedge against future weather uncertainty. It also helps private producers' yields.

But public and private decision makers can have different capital requirements and value systems that differ. Nevertheless, they can still agree on a combination of strategies to try to make whatever climate occurs less damaging. Such an agreement involves a mix of public and private investments, and it involves a mix of market and non-market strategies. Of course, we have to recognize that the mix reflects our value choices based upon how much risk we're willing to take for what benefit paid for or felt by whom. When we recognize that climatic change is essentially a problem of resource redistribution, we realize it is legitimately a political as well as a scientific debate. The best thing that scientists can do is to keep their information base as current and as clear as possible. Political people should not try to use the bad (or good) weather event of the week or the latest research result of the month to justify a value conclusion. We all need to be honest over whether we're pushing values as opposed to reporting on a pure piece of science. The clear separation of scientific issues from individuals' value choices and the explicit recognition of the different investment criteria implied by public strategic - as opposed to private economic - planning are the principal areas that need to be addressed by both public and private decision makers faced with the possible impacts of climatic variations.

EFFECTS OF AIR POLLUTION ON PLANT-FEEDING INSECTS

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The topic of air pollutant-related changes in the success of plant-feeding insects is not new but is currently experiencing a rapid new growth in attention. Losses in plant productivity due to insects are estimated to be billions of dollars each year, and there is increasing evidence showing modification of these pest-related losses by environmental stress of the host plants. One widely distributed stress is air pollution, and it was noted recently that if interactions between pollutants, plants and insects were responsible for only a fraction of these losses, the ecologic and economic consequences could be enormous. Recognition of this has stimulated interest worldwide in research on the subject.

Probably the most appropriate way to begin a discussion of the topic is by briefly identifying what we mean when we speak of air pollution. Air pollution is comprised of a very wide variety of gaseous and solid materials emitted into the air both by natural sources such as volcanic eruptions or decay of vegetation and by human-related activities such as industry, refuse burning and transportation. The major pollutants affecting plants are sulfur dioxide, fluorides and the photochemical oxidants--ozone, peroxyacetyl nitrate (PAN) and oxides of nitrogen. In addition to these, there are numerous minor pollutants including hydrogen chloride which can contribute to acidic precipitation, ethylene which is also a plant hormone, carbon dioxide and carbon monoxide with their well-known effects on plants and animals, various heavy metals, particulates that are active in a physical as well as chemical way, and various hydrocarbons that are involved in photochemical reactions affecting ozone levels.

For at least 60 years there have been hints, suggestions and strong belief that air pollutants can cause outbreaks of plant-feeding insects. This has been based upon numerous correlations observed between some measure of insect presence such as damage or numbers and some measure of pollutant presence such as foliar concentration, damage, or distance from the source. There are several hundred such reports and for those interested, a good sampling of these can be found in the bibliography of Hay (1977) and reviews by Heagle (1973) and Alstad et al (1982). The vast majority of these studies have been conducted in forested areas, and a good example is one concerning outbreaks of the saddleback looper (*Ectropus crepuscularia*) and the spruce budworm (*Choristoneura orae*) in the area of an alumina reduction smelter at Kitimat, British Columbia. The plume from the smelter was channeled primarily up and down a valley, traveling principally in a northerly direction from spring through early fall and in a southerly direction in the winter. A plot of the fluoride content of the trees in the area corresponded to the plume dispersion pattern, as did the area defoliated by these two insects. This led to the suggestion that there was a relationship between the pollution and the pest outbreaks, and the implication that fluoride, the major phytotoxic pollutant in the plume, was responsible.

Table 1. Studies correlating insect populations with presence of air pollution in non-forest habitats.

Plant(s)	Insect(s)	Source of Pollution	Reference
Apple	*Aphis pomonella*, *Paratetranychus pilosus*	Sulfur Plant	Przybylski 1967
Apple, wheat & grasses	General Survey	Sulfur Plant	Przybylski 1974
Hawthorn	*Aphis pomi*	Road Traffic	Fluckiger et al., 1978
Apple, wheat & grasses	General Survey	Road Traffic	Przybylski 1979
Hawthorn, European beech	*Euproctus similis*, *Phalesa bucephala*	Road Traffic	Port and Thompson 1980
Hawthorn	*A. pomi*, *Dysaphis* sp., psyllids	Road Traffic	Braun et al., 1981
Grassland	Thrips	ZAPS (SO_2)	Rice et al., 1978
Grassland	Acrididae	ZAPS (SO_2)	Leetham et al., 1978; McNary et al., 1981

In addition to being typical of the correlative type of study, this is a good example to consider for another reason. As a result of extensive examination of the situation, investigators proposed several hypotheses, each of which could explain the correlation. Some hypotheses postulated effects of a specific component of the pollutant fume, such as weakening of trees by fluoride so that they were unable to resist insect attacks. Others postulated effects of the plume as a whole, such as the emissions having a blanket effect that resulted in a slightly reduced range of temperature extremes favorable to the pests, and still other hypotheses postulated effects not due to the pollution at all, such as the adult moths being carried into the area and dispersed by the same winds that were dispersing the smelter emissions. None of these hypotheses could be proven or disproven, and they serve as an important reminder that, in this and in all similar studies, a correlation does not necessarily mean a cause-effect relationship.

In addition to the large number of such correlations reported in forest ecosystems, there are a few studies of the same type that have been conducted in clutivated plants, along roadways, and in meadows or grasslands (Table 1). These have been conducted primarily in Poland, Switzerland and the United Kingdom. Because of different methodologies used and variations in the completeness of taxonomic determinations and characterization of the field conditions, it is difficult to generalize from these studies. However, a consistent theme is that aphids as a whole seem to benefit from the presence of the pollution while thrips, mites and hymenopterous parasites appear often to be negatively affected.

These correlative-type studies make a valuable contribution both as a body of circumstantial evidence of air pollution affecting the success of plant-feeding insects as well as through the impetus they have provided for additional research. However, cause-effect relationships cannot be demonstrated nor can the causal pollutant(s) be identified without controlled laboratory and field experiments. To date, very few such studies have been reported.

Summarizing results of the controlled investigations is done most easily in the context of how pollutants can affect insect success. They can affect the insects directly by being toxic or by stimulating metabolism. They can also affect the insects indirectly by 1) affecting predators, parasites or pathogens; 2) altering the microclimate or microhabitat; or 3) inducing changes in the host plant.

In terms of direct effects, the toxicity of specific pollutants to insects has been demonstrated in many studies. However, only a few phytophagous insects have been examined, and these are listed in Table 2. A large number of reports concerning the use of compounds such as fluorides and arsenicals as pesticides have been omitted. Often in these studies the concentrations used were extremely high and the durations of exposure were very long compared with the usual pollutant episode in the field. The studies by Feir (1978) and Feir and Hale (1983a) are unique in that she has attempted to use a complex combination of pollutants typical of a particular urban environment. In general, one would conclude from these different reports that plant-feeding insects are relatively insensitive to direct exposure to most gaseous pollutants but can be affected more readily by ingestion of water-soluble forms.

Table 2. Studies on direct effects of air pollutants on plant-feeding insects.

Insect	Pollutant(s)	References
Bombyx mori	Fluoride salts	Fuji and Honda, 1972
Mamestra brassicae	NaF	Weismann and Svatarakova, 1974
Scotia segetum	Naf	Weismann and Svatarakova, 1974
Leptinotarsa decemlineata	NaF	Weismann and Svatarakova, 1974
Onchopeltus fasciatus	SO_2, NO, NO_2, CH_4, CO, & $(NH_4)_2SO_4$	Feir, 1978; Feir and Hale, 1983a,b
Carausis morosus	CO	Baker and Wright, 1977

Table 3. Studies demonstrating cause-effect relations between pollutant-induced changes in plants and insect success.

Plant/Insect	Pollutant	Source
Phaseolus vulgaris/ *Epilachna varivestis*	HF	Weinstein et al., 1973
	SO_2	Hughes et al., 1981
	O_3	Benepal et al., 1979
Glycine max/*E. varivestis*	SO_2	Hughes et al., 1982, 1983

Stimulatory effects of a pollutant that come under the heading of hormesis have been demonstrated in at least three cases. A low level of sodium fluoride greatly stimulated egg production by the confused flour beetle (Johansson and Johansson, 1972), and exposure of house flies to ozone caused dramatic increases in egg production and subsequent population growth (Levy et al., 1972; Beard, 1965). In the only report on a plant-feeding insect, sulfur dioxide stimulated growth and reproduction of the large milkweed bug while both carbon monoxide and nitric oxide stimulated growth (Feir and Hale, 1983b). Many more such examples are likely to be found among phytophagous insects upon closer examination.

Although reduced numbers of predators and parasites in polluted areas have been reported in many field studies, very few controlled experiments have demonstrated cause-effect relations. Inert dusts have been shown to cause mortality of many parasitic hymenoptera, and in the case of the black pineleaf scale, dust-related mortality of the primary parasite is strongly implicated as the main cause of several outbreaks. In another study, a parasitic wasp was found to be insensitive to a high level of the gaseous pollutant sulfur dioxide, introducing the possibility that reductions in parasites attributed to sulfur dioxide have been due either to another pollutant or to a behavioral avoidance of polluted areas rather than to changes in survivorship or reproduction. There are no reports in which the effects of pollutants on predators or pathogens have been examined under well controlled conditons.

Changes in microclimate and microhabitat due to air pollution have also been demonstrated, including changes in leaf temperature and surface characteristics. However, as far as I know, only in studies with tetranychid mites has such a pollutant-induced change actually been shown to alter the success of a herbivore. In these studies (e.g., Fleschner, 1956) mite populations increased greatly in the presence of dust and the increase clearly was not due to any changes in biological control factors or to physical or chemical effects on mite reproduction or longevity.

A final way in which air pollution can affect plant-feeding insects indirectly is by altering the host plant. The only published studies of which I am aware that demonstrate a cause-effect relation between pollutant-induced changes in plants and changes in insect success are listed in Table 3. Weinstein et al. (1973) found that the Mexican bean beetle (MBB) (*Epilachna varivestis*) developed more slowly, grew less, and was less fecund when fed on plants of *Phaseolus vulgaris* fumigated with hydrogen fluoride. We looked at the effect of fumigation of common bean with SO_2 and found no striking differences in beetle growth, development time, survivorship or fecundity (Hughes et al., 1981). However, adult females showed a distinct preference for feeding on fumigated leaves. Benepal et al. (1979) found that adult females of this insect fed more on leaves heavily fumigated with ozone than on non-fumigated leaves. The most extensive work in this area has been that concerning the effects of SO_2 on the soybean/MBB relationship, and since this system is developing into a model, it's worthwhile examining in greater detail what is currently known.

The first tests conducted were designed to tell whether or not plant exposure to the pollutant affected the insect in any way that might lead to increased or decreased population levels. To do this, effects were measured on development time, reproductive rate (as characterized by time to first reproduction, the number of eggs produced per female, and the viability of the eggs), adult longevity and larval survivorship. When fed on fumigated leaves, the larvae developed faster and reached adulthood an average of one day earlier than those fed on non-fumigated plants. Neither larval survivorship nor adult longevity was affected by the treatment, but the effect on fecundity was quite pronounced (Table 4). The time to first eggs laid tended to be shorter on the fumigated leaves, but the variation was so great that this difference was not significant. However, both the number of egg masses laid per female and the number of eggs per mass were significantly higher on the fumigated leaves, resulting in almost twice as many eggs per female over the 18 days of the test. In addition, the viability of these eggs was about 3.5 times greater than that of the control eggs, making the net fecundity about 6.5 times greater on the fumigated leaves. Adult longevity was not affected by treatment over the period of this test.

The effects of plant fumigation on MBB growth and feeding behavior were examined as initial steps in identifying the pollutant-induced changes responsible for altering beetle success. Larval growth was greater on the fumigated leaves with a significant difference in weight evident as early as the second instar. This difference increased as the larvae developed, then decreased slightly at pupation.

To determine how larval growth was being affected, three indices of food consumption and utilization were measured. These were the Relative Growth Rate (RGR), which is the mg weight gained per mg body weight per day, the Relative Consumption Index (RCI), which is the mg leaf tissue ingested per mg body weight per day, and the Efficiency of Conversion Index (ECI), which is the RGR divided by the RCI and represents the efficiency with which ingested food is converted into body substance. When the plants were exposed to a low level of pollutant that had not produced an effect on insect growth in independent tests, no differences between treatments were found for any of the three indices. However, when a dose that had previously produced a growth response in the insect was used, the RCI was significantly higher and the ECI was significantly lower for larvae fed on the fumigated leaves. The RGR was also higher but not with statistical significance.

These results indicate that the increased larval growth observed on fumigated leaves is a consequence of the larvae eating more, as reflected in the higher RCI, rather than of an increase in the nutritional value of the food, which would have been manifested as an increase in the ECI. This sort of response would be expected if the relative level of feeding stimulants increased or that of feeding deterrents decreased. In keeping with this, adult females showed a distinct preference for feeding on fumigated leaves in a standard leaf disc assay.

Table 4. Fecundity of MBB females fed on excised trifoliolate leaves of stage V2 soybeans fumigated for 1 week with 524 $\mu g\ m^{-3}$ of SO_2 or non-fumigated plants.

Determination	Source of foliage[a]	
	Control ($\bar{x} \pm SD$)	Fumigated ($\bar{x} \pm SD$)
Preoviposition Time (Days)	10.4 ± 1.4(5)	9.5 ± 2.1(6) ns
No. of eggs/♀	75.0 ± 33.0(5)	135.0 ± 52.0 P<0.05
No. of eggs/Mass	31.0 ± 17.0(12)	43.0 ± 15.0(19) P<0.05
No. of masses/♀	2.2 ± 0.8(5)	3.2 ± 1.2(6) P<0.001
Time (days Between Egg Masses	4.5 ± 1.7(8)	5.0 ± 0.8(14) ns
Longevity (days) of		
Ovipositing Females	24.0 ± 4.0(5)	25.0 ± 6.0(6) ns
All Females	15.0 ± 10.0(10)	18.0 ± 11.0(10) ns
Foliar S (% dry wt)	0.18 ± 0.03(26)	0.53 ± 0.08(28)

a Numbers in parentheses indicate sample size. ns-Nonsignificant. From Hughes et al., 1982.

Table 5. Fecundity and growth of MBB on control or SO_2-fumigated soybeans under field conditions (Ithaca, 1981).

Treatment	Avg. No. of Progeny/Female	Avg. No. of Eggs Per Female When Test Terminated	Average Prepupal Wt. (mg) Male	Average Prepupal Wt. (mg) Female
Control	85	38	38.1	41.8
Fumigated	128	74	41.1	46.4
P	<.10	<.05	<.02	<.01

The effects of the dose of pollutant on plant response have been studied using the larval growth difference to detect if a particular treatment induced the change(s). When plants were fumigated continuously for 24 hours at concentrations from 0 to 0.7 ppm and given either no recovery time or 24 hours in which to recover from the fumigation, the larval growth increase was found at all concentrations from 0.05 ppm upwards. No strong dose-response relation has been found, with weight gains being only slightly higher at the much higher concentrations of pollutant than at the lower ones. The plants apparently cannot recover rapidly from the fumigation, since the larvae were still significantly larger when fed on those given the recovery period. In another test, the response occurred in six hours or less at 0.5 ppm, and in ongoing work we are finding the effect with only three hours of fumigation at even lower concentrations of pollutant.

In 1981 the interaction between SO_2 and the MBB on soybean was tested under field conditions by placing cages over plants and using a tube fumigation system (Hughes et al., 1983). Control treatments received only ambient air while the fumigated cages received air plus sulfur dioxide. The same number of newly eclosed male and female beetles were introduced into each cage and were left essentially undisturbed for 68 days. After this time all plants and insects were removed and the insects counted. Fumigations occurred on average three times per week for six hours each time and the concentration averaged about 0.14 ppm SO_2 during the period of fumigation. In less than one generation time, the populations were about 1.5 times greater in the fumigated treatments than in the controls (Table 5). An effect on fecundity as opposed to survivorship was indicated by the almost two-fold greater number of eggs found per female alive in the fumigated treatments at the time the test was terminated. Also, the growth response previously seen in the laboratory was observed, with pupae of both sexes being significantly heavier in the fumigated treatments.

These studies establish a cause-effect relation between sulfur dioxide-induced changes in the plant and alteration of the development time, growth, fecundity and feeding preference of the MBB. At least some of these alterations are expected to result in increased population growth, and this possibility is supported by the results of the field test. In addition, since publishing these results I have been told of two situations currently under investigation in which the MBB is a serious pest on soybeans in the vicinity of a source of pollution but not outside of the area affected by the pollutants.

The mechanisms by which pollutants alter the success of insects are of considerable interest. The physiological bases for the direct effects of many pollutants are the subject of numerous toxicological studies and I will not attempt to detail those here. Far less studied have been the mechanisms involved in the indirect effects. Particulates are postulated to affect parasites by disrupting the wax barrier of the integument, resulting in excessive water loss and subsequent death. There are also suggestions of trophic amplification of toxic pollutants, but this has not been clearly demonstrated to be involved in effects on parasites and predators. Similarly, the mechanisms by which microclimate and microhabitat are altered have received very

little attention, and none of the specific pollutant-induced changes in the host plant that affect the insects have been identified.

Even so, outlining some of the major ways in which air pollutants are known to affect plant characteristics of importance to insects has value in stimulating ideas and hypotheses. First, what are these characteristics? Insects depend on plants for behavioral cues involved in feeding and oviposition, for nutrition to support growth and reproduction and for substrate and protection from the physical and biotic environment. Discounting the latter as likely to be affected by air pollutants, any changes in the plant's vulnerability to discovery or in its nutritional quality could have a great impact on the success of the herbivorous insects (Table 6). Involved broadly in both the vulnerability to discovery and the nutritional quality so worthy of separate consideration are the plant defenses.

All of the processes and characteristics listed in Table 6 have been shown to be affected by air pollutants in one way or another. Those involved in the insect's ability to locate the host include the host density and the physical and chemical characteristics that serve as behavioral cues, including color, surface morphology, and chemical attractants, repellents, stimulants, deterrents and arrestants.

Pollutants can alter the nutritional quality of the host in many ways. they can change the plant's nutrition and hence its vigor and resource allocation by altering the soil pH, complexing nutrients, leaching nutrients from the leaves, altering litter decomposition, affecting root symbionts, or by serving as nutrients themselves, as oxides of nitrogen and sulfur have been shown to do under certain circumstances. They can also affect the quality of the host by causing changes in primary metabolites of nutritional importance to the insects or in secondary metabolites that affect feeding behavior and digestibility of the host. They can disturb plant water balance by causing biochemical changes affecting stomatal conductance or, in the case of particulates, by physically impairing closure of stomates. Furthermore, plant vigor can be affected by hormetic activity of pollutants, and stimulation of plant growth by low levels of fluoride, sulfur dioxide, and ozone has been demonstrated. In addition, they can affect the titers of plant hormones, affecting insects both through subsequent changes in the plant and more directly, such as by the demonstrated depression of locust maturation and reproduction caused by the low gibberrellin content of senescent plant tissue.

Pollutants can affect both physical and chemical characteristics of plants that serve as defenses against insects. For example, simulated sulfate acid rain can cause an increase in the density of trichomes, hair-like structures on leaf surfaces that frequently serve a defensive function. Some of the most effective defenses against insects are chemicals whose production and distribution are induced by insect injury to the plant, and pollutants may affect the plant's ability to produce these defenses.

To summarize, the many correlative-type studies form a strong circumstantial case for air pollution altering the success of plant-feeding insects in many

Table 6. Host changes likely to affect insect success.

A. Host Vulnerability to Discovery

   1. Host density

   2. Behavioral cues (physical and chemical)

B. Host Nutritional Quality

   1. Plant nutrition

   2. Levels of plant metabolities

   3. Plant water balance

   4. Metabolic activity (hormesis)

   5. Plant hormones

C. Plant Defenses

   1. Constitutive

      a. Surface morphology

      b. Toughness

      c. "Secondard" metabolites

   2. Induced

habitats, although agroecosystems have not been well represented in past studies. This case is further strengthened by the few controlled experiments that have demonstrated cause-effect relations between specific pollutants or combinations of pollutants and changes in insect behavior or success. Although hypotheses abound, virtually nothing is known definitively about mechanisms by which the pollutants affect the insects, particularly the indirect effects.

What is needed now to assess the actual impact of the interaction on forest and crop productivity and to include it in loss or integrated pest management models? Unless some general principles emerge, such as through studies on the mechanisms, this likely will have to be addressed on a crop-by-crop basis. We need to know which insects are affected, the magnitude of the effect and to what degree any population changes will be offset by natural population regulating processes. Furthermore, we need to know the important "dose" parameters. How should concentrations be measured, as the mean, peak or some other measure? What about duration and frequency of exposures and so on, and what are the "dose" thresholds as well as the dose-response relations? In addition, combinations of pollutants need to be considered rather than simply single components, since literature concerning effects on plants indicates that the combinations often will act synergistically, and seldom would exposure be to a single pollutant.

In terms of the outlook for the future, this also needs to be considered on an area-to-area basis. The current trend in air pollution throughout the U.S. including Illinois is towards decreased emissions. However, such broad regional assessments are too general to be of use in considering effects on insects in forested or agricultural areas. Reductions in emissions in urban areas may bring regional averages down while in specific rural areas the levels might actually be increasing, primarily due to increasing numbers of point sources being located in these areas. Whatever the actual trend might be, I expect the apparent trend over the next decade will be one of more examples being identified of air quality affecting crop losses due to insects and better estimations of the economic impact. With this increased awareness and documentation, this relationship is more likely to become an issue in the siting of pollutant-emitting sources.

REFERENCES

Alstad, D.N., G.F. Edmunds, Jr. and L.H. Weinstein, 1982. Effects of air pollutants on insect populations. Annual Review of Entomology 27: 369-384.

Baker, G.M. and E.A. Wright, 1977. Effects of carbon monoxide on insects. Bulletin of Environmental Contamination and Toxicology 17: 98-104.

Beard, R.L, 1965. Observations on house flies in high-ozone environments. Annals of the Entomological Society of America 58: 404-405.

Benepal, P.S., M. Rangappa and J.A. Dunning, 1979. Interaction between ozone and Mexican bean beetle feeding damage on beans [Abstract]. Annual Report of the Bean Improvement Cooperative 22: 50.

Braun, S., W. Flückiger and J.J. Oertli, 1981. Einfluss eina Autobahn auf den Befall von Weissdorn (Crataegus monogyna) mit Aphis pomi. Mitt. dtsch. Ges. Allg. angew. Ent. 3: 138-139.

Feir, D., 1978. Effects of air pollutants on insect growth and reproduction [Abstract]. Physiologist 21: 36.

Feir, D. and R. Hale, 1983a. Growth and reproduction of an insect model in controlled mixtures of air pollutants. International Journal of Environmental Studies 20: 223-228.

Feir, D. and R. Hale, 1983b. Responses of the large milkweed bug, Oncopeltus fasciatus (Hemiptera: Lygaeidae) to high levels of air pollutants. International Journal of Environmental Studies 20: 269-273.

Fleschner, C.A., 1956. Field approach to population studies of tetranychid mites on citrus and avocado in California: Proceedings Tenth International Congress of Entomology 2: 669-674.

Flückiger, W., J.J. Oertli and W. Baltensweiler, 1978. Observations of an aphid infestation on hawthorn in the vicinity of a motorway. Naurwissenschaften 65: 654-655.

Fuji, M. and S. Honda, 1972. The relative oral toxicity of some fluorine compounds for silkworm larvae [in Japanese]. Journal of Sericultural Science of Japan 41: 104-110.

Hay, C.J., 1977. Bibliography on arthropoda and air pollution. USDA Forest Service General Technical Report NE-24.

Heagle, A.S., 1973. Interactions between air pollutants and plant parasites. Annual Review of Phytopathology 11: 365-388.

Hughes, P.R., A.I. Dickie and M.A. Penton, 1983. Increased success of the Mexican bean beetle on field-grown soybeans exposed to SO_2. Journal of Environmental Quality 12: (In Press).

Hughes, P.R., J.E. Potter and L.H. Weinstein, 1981. Effects of air pollutants on plant-insect interactions: Reactions of the Mexican bean bettle to SO_2-fumigated pinto beans. Environmental Entomology 10: 741-744.

Hughes, P.R., J.E. Potter and L.H. Weinstein, 1982. Effects of air pollution on plant-insect interactions: Increased susceptibility of greenhouse-grown soybeans to the Mexican bean beetle after plant exposure to SO_2. Environmental Entomology 11: 173-176.

Johnasson, T.S.K. and M.P. Johansson, 1972. Sublethal doses of sodium fluoride affecting fecundity of confused flour beetles. Journal of Economic Entomology 65: 356-357.

Leetham, J.W., T.J. McNary and J.L. Dodd, 1979. Effects of controlled levels of SO_2 on invertebrate consumers. IN Bioenvironmental Impact of a Coal-Fired Power Plant, Fourth Interim Report, Colstrip, Montana, E.M. Preston and T.L. Gullett, eds. EPA-600/3-79-044, U.S. Environmental Protection Agency, Washington, D.C., pp. 723-763.

Levy, R., Y.J. Chiu and H.L. Cromroy, 1972. Effects of ozone on three species of Diptera. Environmental Entomology 1: 608-611.

McNary, T.J., D.G. Milchunas, J.W. Leetham, W.K. Lauenroth and J.L. Dodd, 1981. Effect of controlled low levels of SO_2 on grasshopper densities on a northern mixed-grass prairie. Journal of Economic Entomology 74: 91-93.

Port, G.R. and J.R. Thompson, 1980. Outbreaks of insect herbivores on plants along motorways in the United Kingdom. Journal of Applied Ecology 17: 649-656.

Przybylski, Z, 1967. Effect of gases and vapors of SO_2, SO_3, and H_2SO_4 on fruit trees and certain harmful insects [in Polish]. Postepy Nauk Rolniczych 14: 111-118.

Przybylski, Z., 1974. Results on observations of the influence of sulfurous gas on fruit trees, shrubs and arthropods around the sulfur mines and processing plants in the Tarnobrzeg region [in French, English summary]. Environmental Pollution 6: 67-74.

Przybylski, Z., 1979. The effects of automobile exhaust gases on the arthropods of cultivated plants, meadows, and orchards. Environmental Pollution 19: 157-161.

Rice, P.M., L.H. Pye, R. Boldi, J. O'Loughlin, P.C. Tourangeau and C.C. Gordon, 1979. The effects of "low level SO_2" exposure on sulfur accumulation and various plantlife responses of some major grassland species on the ZAPS sites. IN Bioenvironmental Impact of a Coal-Fired Power Plant, Fourth Interim Report, Colstrip, Montana, E.M. Preston and T.L. Gullett, eds. EPA-600/3-79-044, U.S. Environmental Protection Agency, Washington, D.C., pp. 494-591.

Weinstein, L.H., D.C. McCune, J.F. Mancini and P. van Leuken, 1973. Effects of hydrogen fluoride fumigation of bean plants on the growth, development and reproduction of the Mexican bean beetle. IN Proceedings of the 3rd International Clean Air Congress, Dusseeldorf, 1973, pp. A150-A153.

Weismann, L. and L. Svatarakova, 1974. Toxicity of sodium fluoride to some species of harmful insects. Biologia (Bratislava) 29: 847-852.

THE ROLE OF MOVEMENT IN THE DYNAMICS OF HIGHLY MOBILE ORGANISMS

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GENERAL CONCEPTS

That organisms move is not new knowledge. Several extensive works (e.g., Johnson, 1969; Baker, 1978; Gautreaux, 1980) have focused on the details of individual and population movements with a myriad of examples. Recent symposia have concentrated on relating state-of-the-art information about movement (migration and/or dispersal) for select groups of organisms (Vaughn et al., 1978; Rabb and Kennedy, 1979; Gunn and Rainey, 1979). Reviews of these works reveal that, while many facts are known about certain organisms, very little definitive information exists relative to the role movement plays in the overall population ecology of mobile species. This is especially true for most of the night flying, polyphagous insect crop pests.

Much discussion has occurred in recent years about methods usable for protection of crops against pest species. While many terms have been utilized, the term that seems to be in the current mainstream is noted as integrated pest management (IPM). Philosophically, IPM refers to use of a myriad of ways to deal with pests (called tactics) which are blended into an overall approach (called a strategy). This is as opposed, for example, to use of a single tactic (a chemical pesticide). Numerous authors (Rabb and Gutherie, 1970; Metcalf and Luckmann, 1975; Apple and Smith, 1976; Smith and Pimentel, 1978; Bottrell, 1979; Huffaker, 1980; Barfield and Stimac, 1980) have waxed eloquent on the IPM concept and the need for a "balanced attack." As we shall see, current materializations of the "IPM approach" in real world agricultural systems must overcome paramount problems when the pests of concern are highly mobile.

While documentation exists that certain species of plants (weeds) and pathogens engage in at least passive movement among plant communities, the predominance of literature on mobile "pest" species appears to be on insects. Most of the examples and citations used in this paper will be drawn from the entomological literature; however, the reader should note that, in concept, the thesis will be expandable to other types of mobile species. This is important if, as I will propose, a blueprint can be drawn for addressing mobile species (regardless of the particular type of species concerned). To successfully present this so-called blueprint, I must (1) present a case for the importance of movement in the dynamics and potential "pest status" of select insects, (2) elucidate the experimental problems which confront the researcher desiring to address such species, (3) provide conceptual and experimental evidence of research on movement in insects, and (4) state explicitly a set of objectives and approaches which I feel are crucial to an overall investigation of the role of movement in insect pest dynamics. Of paramount importance to my arguments is the feeling that the ability to UNDERSTAND the ecology and dynamics of mobile insects is a PREREQUISITE to development of robust IPM strategies against them.

THE CASE OF MOBILE INSECT PESTS

Southwood (1962) and Rabb and Stinner (1979) discussed the ecological framework in which mobile arthropods function. Patterns of occurrence of insects in space and time, by and large, have been difficult to interpret (see Stinner et al., 1983, for review). This is highlighted by the general lack of information among agriculturists about origins and "destinations" of insect pests before and after they occur in specific crops needful of protection. A good example of this situation can be seen in cropping systems in the southeastern United States.

A typical agroecosystem in the southeastern USA might consist of mixtures of corn, peanuts and soybean. Discontinuities in plant/harvest dates result in a more or less continuum of host plant material being available for a complex of pest organisms. Barfield (1979) details such a complex. The first crop in this sequence is corn, and this crop is invaded (from unknown sources) early in the phenological cycle. After up to three generations of key pests [e.g., the fall armyworm, *Spodoptera frugiperda* (J.E. Smith)], corn begins to senesce and the pest complex emigrates to other available host plants. Evidence exists (Linker, 1980) that a density-dependent, functional response occurs in the natural enemies (particularly the predators) of defoliators like the fall armyworm; thus, with some lag time these natural enemies follow their prey into new plant communities. The point is that, from the pest complex's perspective, a series of host plants, linked by movement of the pests, exists. However, from the typical agriculturist's perspective, a series of independent, unlinked crops exists and each crop is treated, with respect to the design of IPM strategies for these mobile pests, as if it were an island. Others have argued that this situation has resulted in the design of unilateral crop protection schemes for individual crops, not cropping systems as should be the case (see Barfield and Stimac, 1981; Barfield et al., 1980; Barfield, 1979). The important point to the present argument is that agricultural researchers have not focused on two major questions which are crucial to understanding the role that mobility plays in "creating" situations where insects can become pests. These are as follows (from Barfield and Stimac, 1981):

1. How are crop-insect system boundaries defined in terms of environment, mobility and diversity of acceptible host plants?

   Answers to this question are crucial because, for IPM strategies to be robust (i.e., useful in space and time), they must be functions of the life system of target organisms. The more mobile the organism, the wider the boundaries of the life system over which an IPM strategy must work.

2. How are crop systems coupled through flows of pest insects (or other organisms) and beneficial organisms among crop and non-crop hosts?

   If individual crops are not treated as components in the context of an ecological system, then what results, in essence, is that agriculturists are designing IPM programs to "treat the symptoms," not solve the problem.

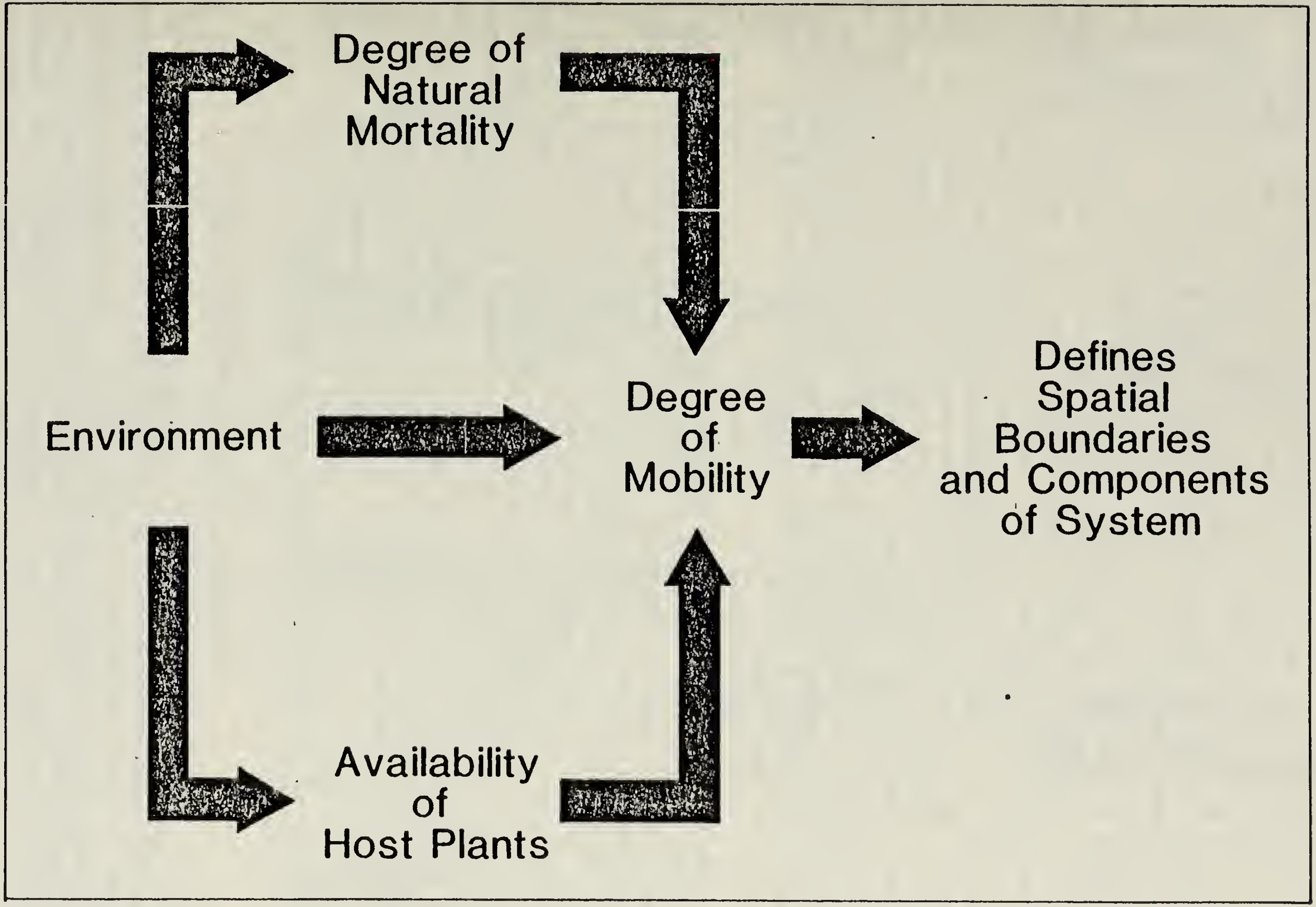

Figure 1. Relationship of environment, host plant biology, and natural mortality to the boundaries and complexity of the life systems of mobile insects. Taken verbatim from Barfield and Stimac (1981).

Conceptually, the mechanisms potentially responsible for dictating movement patterns in mobile insects are depicted in Figure 1 (verbatim from Barfield and Stimac, 1981). Here, the degree or mobility (which dictates the size of the life system) can be strictly a function of physical environment. In this case, cues like day length, temperature, wind speed or direction, etc., might stimulate or stop flight. Further, the availability of host plants, each with their unique phenologies/physiologies, may be the primary driving force behind movement patterns. In the last case presented, the quantity of natural mortality inflicted might also serve as a "cue" to initiate movement. It should be obvious that complex combinations of these three mechanisms are possible. For example, which host plants and natural enemies are present may well be a function of physical environment; thus, the effects of "weather" may be filtered through host plants and mortality to the impact on mobile pest species. Whichever is the case (and very little is known about this area), the fact remains that unless the mechanisms driving the initiation, duration and termination of flight are understood, crop protection specialists are doomed to continue to develop localized IPM strategies for mobile species. The "spatial" and "pest" hierarchies presented by Stimac and Barfield (1979) illustrate this quite effectively, and the inability to predict the occurrence of damaging infestations of fall armyworm (Barfield et al., 1980) due to the almost total lack of information on what ecological mechanisms drive movement, depicts where agriculturists are relative to dealing with mobile insect pests.

The complexity that may be associated with assessment of the impact of colonizing species, originating from multiple sources and immigrating into a given crop, is shown in Figure 2. A field level sampling tool (e.g., a light or pheromone trap) may capture genetically different groups of individuals of the same species. These differences may be associated with different parametric values for consumption, development, reproduction, and susceptibility to mortaility from a variety of factors. If biological information on these processes is to be used, for example, as impingements on a realistic crop growth model, average values may not be sufficient for accurate assessment. While these are a lot of "ifs," the inability to forecast damage (indeed, to even relate trap catch to in-field densities) indicates a severe lack of biological understanding about both the mobile pests and the system(s) within which they are moving. This fact is depected also in Stinner et al. (1983). To illustrate the state-of-the-art for detailed knowledge about mobile insect pests, we turn now to an example. Herein, both the problem and a possible blueprint for attacking the problem can be elucidated.

A BIOLOGICAL MODEL FOR MOVEMENT STUDIES

The velevetbean caterpillar (VBC), *Anticarsia gemmatalis* Hubner, is an excellent model through which to elucidate the complexities of studying movement of pest organisms. The VBC (Figure 3) is a noctuid (night flying) moth whose larval stages can be serious pests of a number of crops (e.g., soybeans, peanuts). This insect feeds principally on members of the family Leguminosae and thus displays a high degree of polyphagy (i.e., feeds on multiple hosts). Recent research (Stimac et al.,* unpub.) has shown that the

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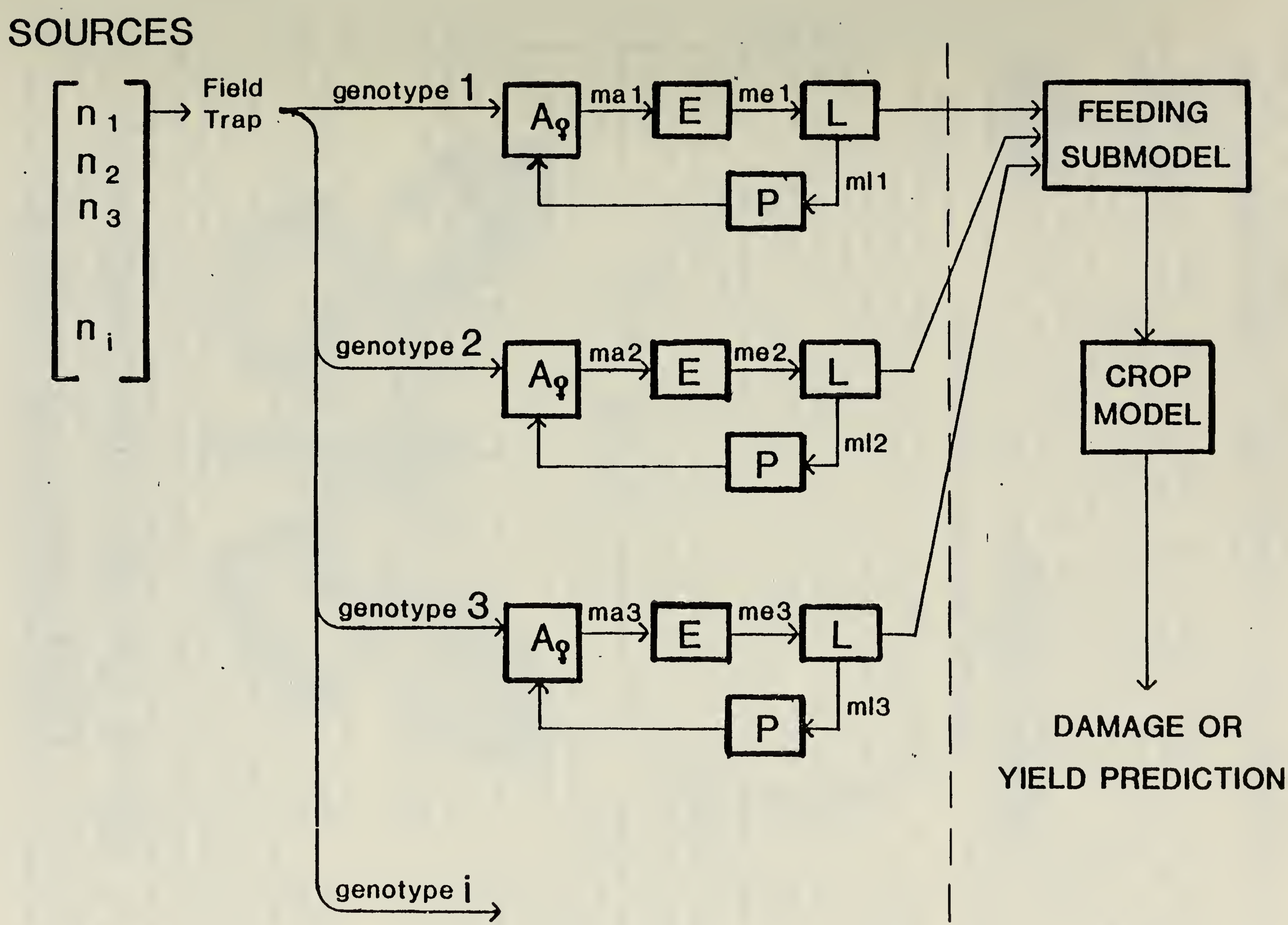


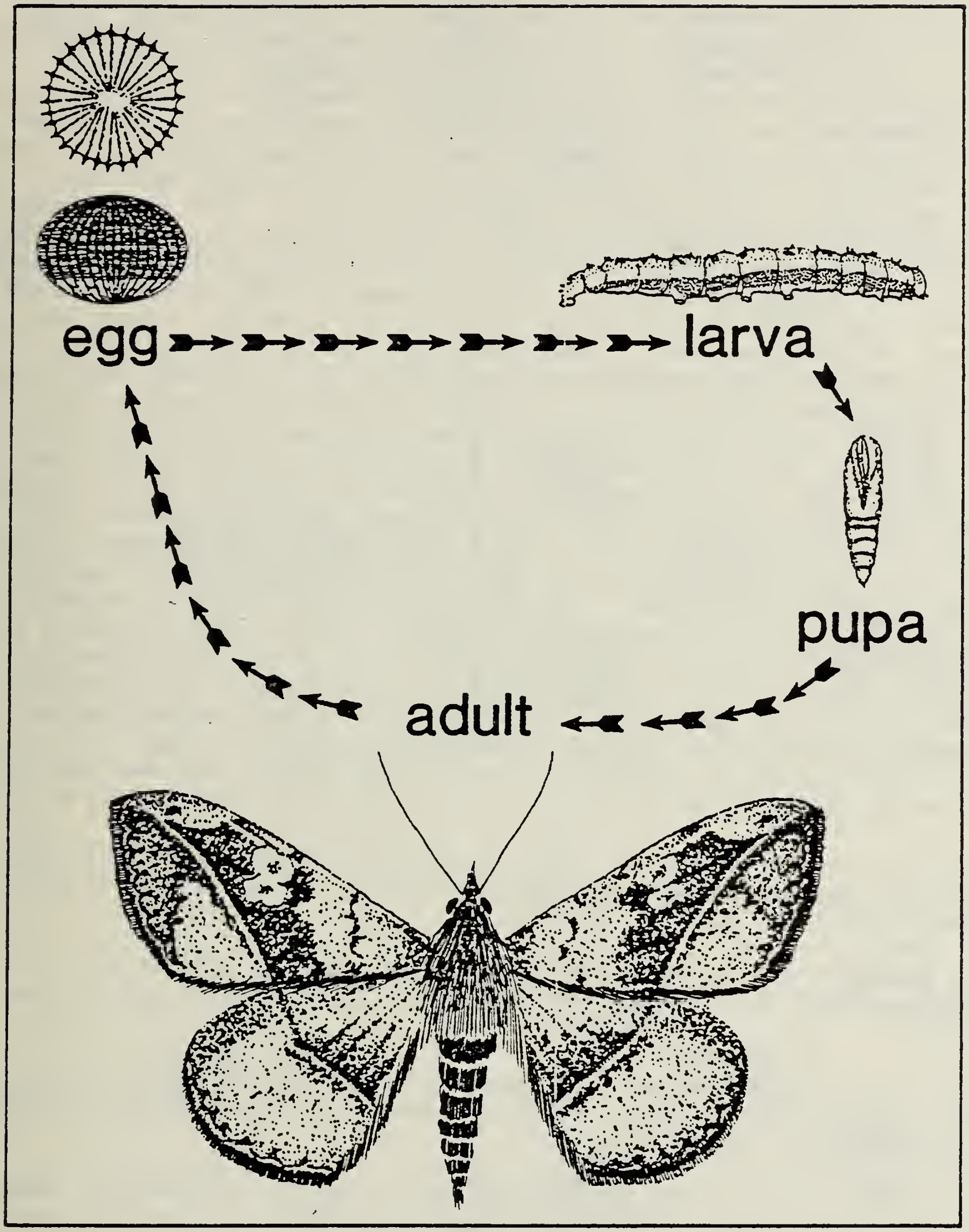
Figure 2. Conceptualization of the differentiation among moths caught in some trap device; ma = mortality of adults; me = mortality of eggs; ml = mortality of larvae; various feeding rates will impact differentially on group growth and yield.

VBC is not capable of surviving winter temperature regimes even as far north as Gainesville, Florida in an "average" winter. Details relevant to VBC overwintering and movement have been outlined (see Rabb and Kennedy, 1979).

Each spring, velvetbean caterpillar appears in plant communities (some of which are crops) much further north than where it is capable of surviving the winter. The obvious process by which the VBC is able to invade these plant communities from some overwintering habitat is MOVEMENT. Investigation into the biology of VBC relative to crop protection reveals that very little information exists which could be used to forecast the timing and magnitude of influx of the VBC at any given site. This is true also for the general complex of mobile moths (see Rabb and Kennedy, 1979; Stinner et al., 1983) typified by the VBC. Barfield et al. (1980) discuss, in detail, why such predictions of influx patterns are not now possible.

Movement (as a process) of VBC can be driven by a number of factors (see Figure 1). First, movement can be a direct function of components of physical environment (see Stinner et al., 1983; Rabb and Kennedy, 1979, pp. 104-47). In this case, variables like wind speed and direction, photo period or temperature can result in more or less movement. Second, movement can be related to host plant. If some critical accumulation of nutrients is needed for development of "flight fuel" and if those nutrients can be acquired only through consumption of certain host plants, then the propensity to move may be related to which host plant is eaten. Third, movement may be linked to natural mortality. If, for example, density is the critical factor which induces a population of moths to emigrate, then a high level of natural mortality may never allow some populations to build to sufficient numbers to evoke movement. Worthy of note is that complex combinations of these three main "movement stimuli" are also possible, indeed probable. For example, physical environment affects the differential survival of the VBC's host plants. As some regimes are too harsh, only certain of the host plants available to the VBC survive. Within those host plants are natural enemies (predators, parasites, pathogens) which are also differentially surviving in relation to weather. Thus, it may well be true that weather acts on organisms like the VBC THROUGH its host plants and natural enemies. Whichever is reality, a mosaic of host plants differentially capable of acting as sources for mobile VBC moths exists in any given year.

As the VBC moves among host plant communities, it inevitably ends up in crop systems. Detecting that its influx even occurs is one problem, although various kinds of traps have been developed and work for "presence or absence" detections (see Croft, 1979; Lingren, 1979; Rabb and Kennedy, 1979). A second, and probably more important, issue is evaluating whether or not a given influx will result in a "pest situation." This involves a combined look at influx and site mortality. A recently developed simulation model (see Wilkerson et al., 1982) of soybean plant growth has been developed at the University of Florida. The model is biologically sensitive to water stress, defoliation and weather and has, among others, a sub-model representing VBC damage. This has afforded the capability of evaluating the importance of elect characteristics of the VBC relative to plant damage. Through a series of simulations, we varied VBC influx (timing and magnitude) over a broad range of plant ages and weather patterns. What was clearly evident was



Velvetbean caterpillar life cycle (Anticarsia gemmatalis)

Figure 3. Graphical depiction of the life history of the velvetbean caterpillar.

that a given influx rate resulted in an economically damaging population only at a certain plant ages and only in the absence of a certain amount of mortality on the immature stages produced by the immigrating VBC adult females. What this means is that for us to develop robust management strategies against pests like the VBC, we must understand the ecological processes which determine when and how many moths we can "expect" and whether or not those moths are capable of producing damaging levels in the next generation. Some sites, for example, may house higher levels of natural enemies and thus be able to absorb more influx before a pest problem occurs. This is discussed in much more detail in Stimac and Barfield (1979) and Barfield et al. (1980) and is presented conceptually in Figure 4. From multiple sources (Ni), moths immigrate into various geographical locations some of which already contain relatively high levels of natural mortality factors (predators, parasites, pathogens, inclement weather). These areas thus have a "high buffering capacity" (HBC) and can absorb a relatively large influx of pests without the result being a true "pest situation." Other areas have a relatively low density of such natural mortality factors and thus have a "low buffering capacity" (LBC). Here, the immigrants can reproduce more effectively and reach some critical density level for infliction of economic loss. Economic loss may occur in both HBC and LBC sites; however, the time necessary for such loss to occur is significantly longer in HBC sites. After some initial influx, HBC sites may be invaded (in time) both from the original source(s) and from neighboring LBC sites. The point is that the interplay between immigration (and subsequent population increase) and site mortality must be understood if one is to assess the impact that a given influx will have on site-specific "pest status." Such currently is not known for most species (see Barfield et al., 1980; Rabb and Kennedy, 1979). What appears needed is a re-thinking of the major problems which must be resolved if we are to understand the ecology and dynamics of mobile pest species and then use that understanding to design robust management strategies for crop protection.

To arrive at the aforementioned UNDERSTANDING which should serve as a prerequisite for the design of management strategies, the following difficult experimental problems must be resolved:

1. How do you relate the number of adult moths caught in a light or pheromone trap to the number of moths actually in a site (e.g., a crop field)?

2. How do you relate the number of moths in a field to the number of eggs in that field? Implied also is an understanding of the mortality inflicted by a complex of natural enemies.

3. Since moths like the VBC fly at night and at higher altitudes (as opposed to many butterflies which are day fliers and fly in the boundary layer), how do you quantify the overall moth population capable of invading crops?

4. How do you determine where the moths are coming from, since their polyphagous nature makes potential sources spread out over wide geographical areas? If you cannot tie an emigrant moth at source A to an imigrant moth at sink B, how can you get "proof positive" of sources?

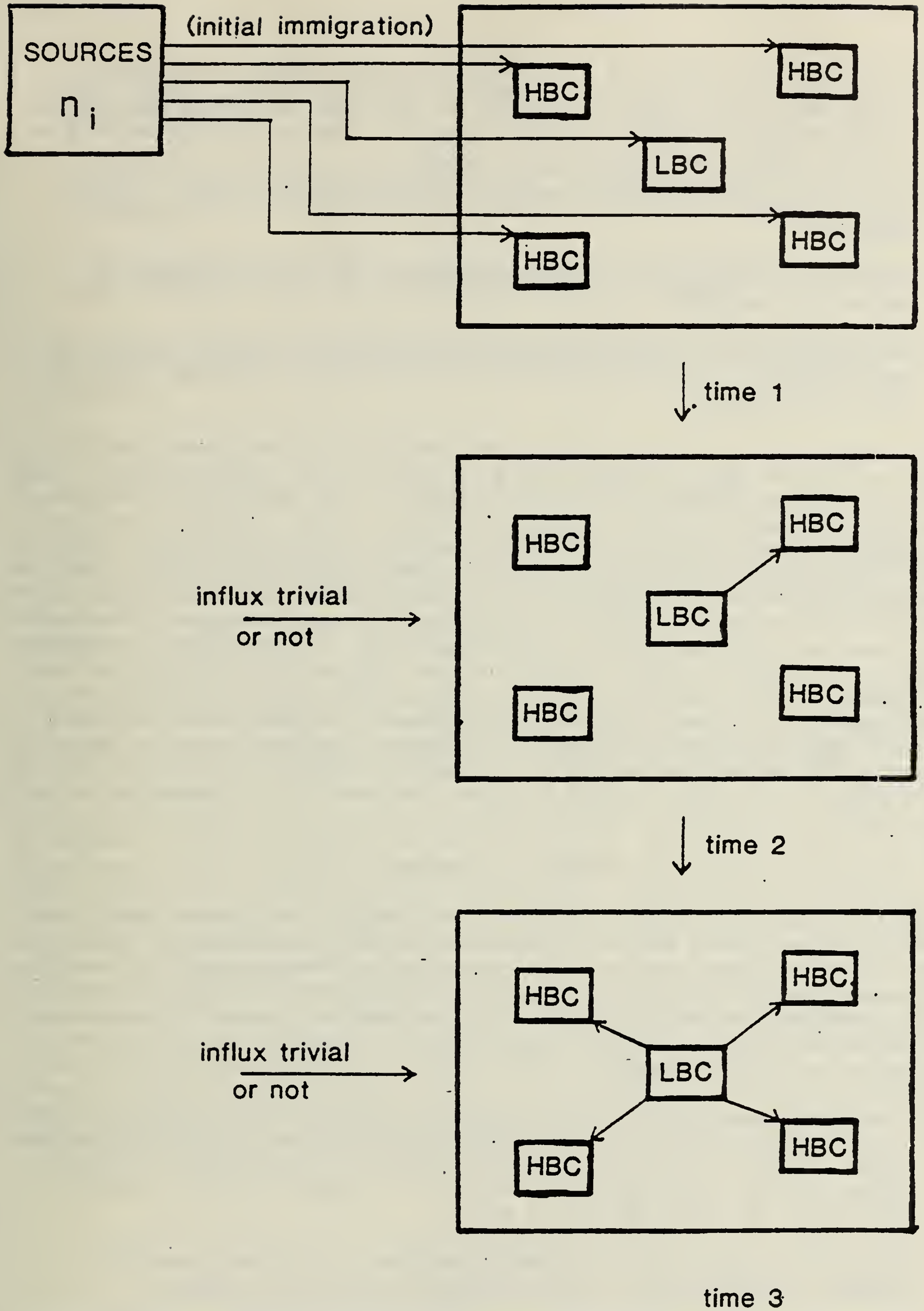


Figure 4. Conceptualization of the relative contribution to "pest outbreaks" made by immigrating moths into sites with low (LBC) versus high (HBC) buffering capacity provided by resident natural enemies.

5. If you want to use sophisticated tools like radar to monitor moth flight as an indicator of #3 above, how do you tell species A from species B on a radar screen (see Vaughn et al., 1978)?

6. How do you evaluate whether or not a given influx will cause a pest problem?

7. How do you relate wide-area weather patterns to passive movement of moths like the VBC?

8. How do you establish wide-area monitoring schemes to detect patterns of moth movement; i.e., when and where do you allocate samples? With what tool do you sample?

These eight areas have been (and are) the subjects of experimentation; however, sufficient data to address the ecological issues presented earlier have not yet resulted. Gregory and Barfield (unpub.) have developed techniques and addressed quantitatively the relationship of light trap catch (relative estimates) to in-field densities (absolute) of VBC adults and eggs. Radar (see Vaughn et al., 1978; Wolf, 1979) has been investigated as a tool to measure migration route and density but has not proven overly promising to date (see Stinner et al., 1983). Few ecologically relevant models like the one presented by Wilkerson et al. (1983) exist as tools to assess the pest potential of migrant moths. A review of the "actograph" literature and the development of an improved device for measuring VBC flight and oviposition simultaneously is given by Wales (1983); however, problems with interpretation of tethered flight data remain paramount to use of such tools. What appears to be needed desperately is a concentrated effort on a few target species and not the multitude of unilateral efforts now so predominant.

AN EXAMPLE OF EXPERIMENTATION

Details of the complications which must be addressed in studying mobile pest insects can be seen in the work of Gregory and Barfield (unpub.). Their major objectives have been to study inter-field movement of the VBC; however, they concluded early that if they could not thoroughly understand within field dynamics they had little chance of deciphering between field dynamics. The following nine sets of experiments had to be conducted en route to an understanding of site dynamics:

1. A weatherproofed light trap (pheromone for the VBC has not been produced commercially), operated on a reliable electrical supply in the field, had to be acquired. Trap catch was checked daily and VBC adults were separated from all other organisms caught. This meant a reliable identification key for adult VBC had to exist;

2. Adult VBC caught in the trap had to be "aged." This was necessary because it was felt that age represented reproductive status;

3. A reproductive rate had to be determined for each age category of adult moths. This was necessary to relate potential oviposition to adult age structure actually in that field;

4. A method for estimating absolute density of adult VBC had to be derived. This allowed establishment of a relationship between trap catch and actual density.

5. A method for estimation of absolute density of VBC eggs had to be derived. This allowed comparison of model predicted and actual egg densities;

6. A key for identification of Lepidoptera eggs in soybeans had to be compiled so we could separate VBC eggs from all others;

7. A reliable method for measuring local weather had to be acquired so that we could use local weather as a "switch" for turning on and off oviposition;

8. VBC egg mortality had to be measured; and

9. An oviposition model had to be constructed and validated.

The point is that nine complex sets of experiments had to be conducted to decipher interrelationships between movement and mortality at just one site. We have found no other noctuid that has been studied this intensively; thus, agriculturists are not now addressing the complexity of experimentation necessary to understand the role of movement in pest dynamics.

If scientists charged with developing integrated management plans for pests like the VBC do not address these issues, then little hope for development of robust management schemes against highly mobile, polyphagous organisms exists. After all, robustness (i.e., a plan that works through space and time) would appear to be the aim of crop protection. A species closely related to the VBC, the fall armyworm [Spodoptera frugiperda (J.E. Smith)], is a member of the same complex of mobile noctuids inflicting damage to crops in the southeastern USA. Deficiencies in information necessary to predict annual patterns of infestation from this insect, just as outlined above for the VBC, also exist (see Barfield et al., 1980). However, as the VBC is a "perienniel pest," the fall armyworm can be classified as a "boom or bust" pest, i.e., in some years it is devastating and in some years it is not even a pest. It, too, is mobile and polyphagous, feeding primarily on grasses (Leguminosae). From all indications, much insight could be gained into the role of movement as a process in the dynamics and "pest status" of noctuid species by a comparative study of VBC and fall armyworm. If such studies are not on the agenda soon, agriculturists (as elucidated by Stimac and Barfield, 1979) will continue to "treat the symptoms" and not solve the problems. This is especially true where mobile, polyphagous pest species are concerned.

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REFERENCES

Apple, J.L. and E.F. Smith, eds., 1976. Integrated pest management. Plenum Press, New York. 200 pp.

Baker, R.R., 1978. The evolutionary ecology of animal migration. Holmes & Meier Pub., Inc., New York. 1012 pp.

Barfield, C.S., 1979. Multiple crop IPM models for economic Lepidoptera: present status and future needs, pp. 107-23. IN Proc. FAO Conf. on use of radiioisotopes in entomol. and IPM. [H. Cromroy, ed.] University of Florida, Gainesville. 336 pp.

Barfield, C.S. and J.L. Stimac, 1980. Pest management: an entomological perspective. Bioscience 30: 683-9.

Barfield, C.S. and J.L. Stimac, 1981. Understanding the dynamics of polyphagous, highly mobile insects, pp. 43-6. IN Proc. Intern'l. Cong. Pl. Protec., Washington, D.C. [T. Kommendahl, ed.]. Burgess Pub. Co., vol. 1, 411 pp.

Barfield, C.S., J.L. Stimac, and M.A. Keller, 1980. State-of-the-art for predicting damaging infestations of fall armyworm. Fla. Entomol. 63: 364-75.

Bottrell, D.G., 1979. Integrated pest management. Rpt. for Council Environ. Quality. U.S. Gov't. Print. Office No. 041-011-00049-1, Washington, D.C. 120 pp.

Croft, B.A., 1979. Use of pheromone traps to monitor long-range movement of Lepidoptera, pp. 316-25. IN Movement of highly mobile insects: concepts and methodology in research [R.L. Rabb and G.G. Kennedy, eds.]. N.C. State Univ. Press, Raleigh, N.C. 456 pp.

Gauthreaux, S.A., Jr., ed., 1980. Animal migration, orientation, and navigation. Academic Press, New York. 387 pp.

Gunn, D.L., and R.C. Rainey, eds., 1979. Strategy and tactics of control and migrant pests. The Royal Society of London. Univ. Press, Cambridge. 240 pp.

Huffaker, C.B., ed., 1980. New technology of pest control. John Wiley & Sons, New York. 500 pp.

Johnson, C.G., 1969. Migration and dispersal of insects by flight. Methuen & Co. Ltd., London. 763 pp.

Lingren, P.D., 1979. Light traps vs. other physical and mechanical trapping devices, pp. 242-8. IN Movement of highly mobile insects: concepts and methodology in research [R.L. Rabb and G.G. Kennedy, eds.]. N.C. State University Press, Raleigh, N.C. 456 pp.

Linker, H.M., 1980. An analysis of seasonal abundance and sampling procedures for the major defoliating Lepidoptera in peanuts and soybeans in north Florida. Ph.D. Disser., Dept. Entomol. & Nematol., Univ. of Florida, Gainesville. 165 pp.

Metcalf, R.L. and W. Luckmann, eds., 1975. Introduction to insect pest management. John Wiley & Sons, New York. 587 pp.

Rabb, R.L. and F.E. Gutherie, eds., 1970. Concepts of pest management. Proc. of Conf., N.C. State Univ., Raleigh, N.C., March 25-7, 1970. N.C. Stae Univ. Press. 242 pp.

Rabb, R.L. and G.G. Kennedy, eds., 1979. Movement of highly mobile insects: concepts and methodology in research. Proc. of a Conf., N.C. State Univ., Raleigh, N.C., April 9-11, 1979. N.C. State Univ. Press. 456 pp.

Rabb, R.L. and R.E. Stinner, 1978. The role of insect dispersal and migration in population processes, pp. 3-16. IN Radar, insect population ecology, and pest management [C.R. Vaughn, W. Wolf, and W. Klassen, eds.]. NASA Conf. Pub. No. 2070, 249 pp.

Smith, E.H. and D. Pimentel, eds., 1978. Pest control strategies. Academic Press, New York. 334 pp.

Southwood, T.R.E., 1962. Migration of terrestrial arthropods in relation to habitat. Biol. Rev. 37: 171-214.

Stimac, J.L. and C.S. Barfield, 1979. Systems approach to pest management in soybeans, pp. 249-59. In Proc. World Soybean Conf. II, Raleigh, N.C. [F.T. Crobin, ed.]. Westview Press, Boulder, CO. 897 pp.

Stinner, R.E., C.S. Barfield, J.L. Stimac, and L. Dohse, 1983. Dispersal and movement of insect pests. Annu. Rev. Entomol. 28: 319-35.

Stinner, R.E., K. Wilson, C. Barfield, J. Regniere, A. Riordan, and J. Davis, 1982. Insect movement in the atmosphere, pp. 193-209. IN Biometeorology in integrated pest management [J.L. Hatfield and I.J. Thomason, eds.]. Academic Press. 491 pp.

Vaughn, C.R., W. Wolf, and W. Klassen, eds., 1978. Radar, insect population ecology, and pest management. NASA Conf. Pub. No. 2070. 249 pp.

Wales, P.J., 1983. Activity of velvetbean caterpillar moths as recorded by a new actograph. M.S. Thesis, Dept. Entomol. & Nematol., Univ. of Florida, Gainesville. 103 pp.

Wilkerson, G.G., J.W. Jones, K.J. Boote, K.T. Ingram, and J.W. Mishoe, 1983. Modeling soybean growth for crop management. Trans. ASAE 26: 63-73.

Wolf, W., 1979. Entomological radar studies in the United States, pp. 263-71. IN Movement of highly mobile insects: concepts and methodology in research [R.L. Rabb and G.G. Kennedy, eds.]. N.C. State Univ. Press, Raleigh, N.C. 456 pp.

MODELS FOR PREDICTING THE EFFECTS OF CLIMATE ON INSECT PESTS

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There are many species of insects in this world, 700,000 at least. One hundred thousand or so occur in the United States, but by no means are all of them pests. Our best estimates indicate that we may have somewhere around 150 to 200 species that frequently cause damage to our crops or to our persons or to our belongings and that there are another 450 or 500 species that occasionally cause damage. The notion of pest is a man-made concept: there are lots of species out there that we don't call pests because they're not bothering us. But if we were a dog or a chimpanzee or a tree, we would consider different species to be pests than we do today.

I think it's also important in the context of this conference to think about some of the changes in climate that have taken place over the last several thousand years and how species that we consider pests today certainly would not have been pests several hundreds or thousands of years ago, even though they were present. The same will certainly be true in the future. Many of the species that we consider pests today won't be very important in the future, not because of anything we do to them, but just because of changes in the environment. The species that do well under one set of circumstances may not do as well after a climate change.

There are several things to consider when we ask why an insect is a pest. A particular species may be important to us because of the number of organisms that are out there, or it may be important at a particular time of the year because of its age distribution; that is, only certain-aged individuals cause us problems. Adults of some species cause problems whereas larvae don't, and vice versa. Furthermore, the feeding rate at any point in time determines whether or not a given number of individuals is important. I'm thinking in terms of insects that affect our crops and that will be the context of my talk this afternoon.

From the point of view of the crop, even though we may have these insects there in a particular number and of the right age distribution and so on, if the crop is not at the right stage of growth, this species may not be considered a pest. In fact, if the crop is growing very rapidly and not under any particular stresses, we may not have a situation where we would call this insect a pest. So this business of predicting insect problems seems at least as complicated as predicting the weather. It might be easier, though, because it's a little easier for us to go out and see our insects, and in spite of what Carl Barfield just said, they don't move around quite as much as weather systems do. Many species of insects are relatively sedentary and stay in one place for a fairly long period of time. If we go out and observe how many pests we have today, I can pretty well predict how many I'm going to have tomorrow and the next day and two weeks after that, probably a little better than I can predict what the weather's going to do.

At any rate, predicting which pests are going to be problems in the near future means that we have to be able to predict many things about the system. I'm not going to talk about the crop very much today but you should understand that for any of our insect-forecasting systems to be successful at predicting how much damage a pest will cause, we must have a good crop model. We can't predict how much damage a species is going to do unless we know how it interacts with the crop, and that requires understanding as much if not more about the crop than about the insect itself.

As Carl mentioned, there are five general processes that we have to consider when we're talking about insect population dynamics, and if we're going to develop predictive models, we need to have models for all five of these processes. One of the important things that an insect does is feed on our crop, so we need a model that predicts feeding rate. Secondly, insects age; they molt as they go through their various life stages, moving from egg to immature stage and eventually to adult. Thirdly, they reproduce through the process of mating and laying eggs. Fourthly, they continually face the threat of death. Every day they must face predatory spiders, potentially fatal diseases and perhaps insecticides. And of course there are all sorts of other threats to survival. Finally we come to this business of how an insect gets from one place to another: we have to model dispersal and movement.

Models can be classified into these three general categories: descriptive, explanatory and predictive. We'd like to have predictive models. It's easiest to have predictive capability if our models are explanatory, and by explanatory I mean that they actually describe the population dynamics in terms of the life processes that go on in the ecological system. If we have a model that includes birth rate, aging, the effects of various environmental conditions on oviposition rate, then that would be an explanatory model. An example of a descriptive model is the one Freeman (1977) proposed for movement.

$$\log Y = a - b\sqrt{x} - ht + cx \log t$$

where Y = density at time t, and
x = distance from rebase point.

This equation fits the observed relationship between numbers, distance and time rather well. While the coefficients a, b, h, and c in this regression equation may have some approximate biological meaning, they don't really capture the processes that are involved. Therefore, to use this model to try to forecast or predict what will happen in the future is fraught with all sorts of difficulties and probably won't get us very far.

The alternative is something similar to what Carl Barfield was talking about with his computer simulation model. Figure 1 presents one that Taylor (1979) proposed when he was working with migration of the desert locust out of Africa on its northward movement into Great Britain. He used a model containing this sort of logic to simulate the movement of the population, the flight out across the ocean and up toward Great Britain.

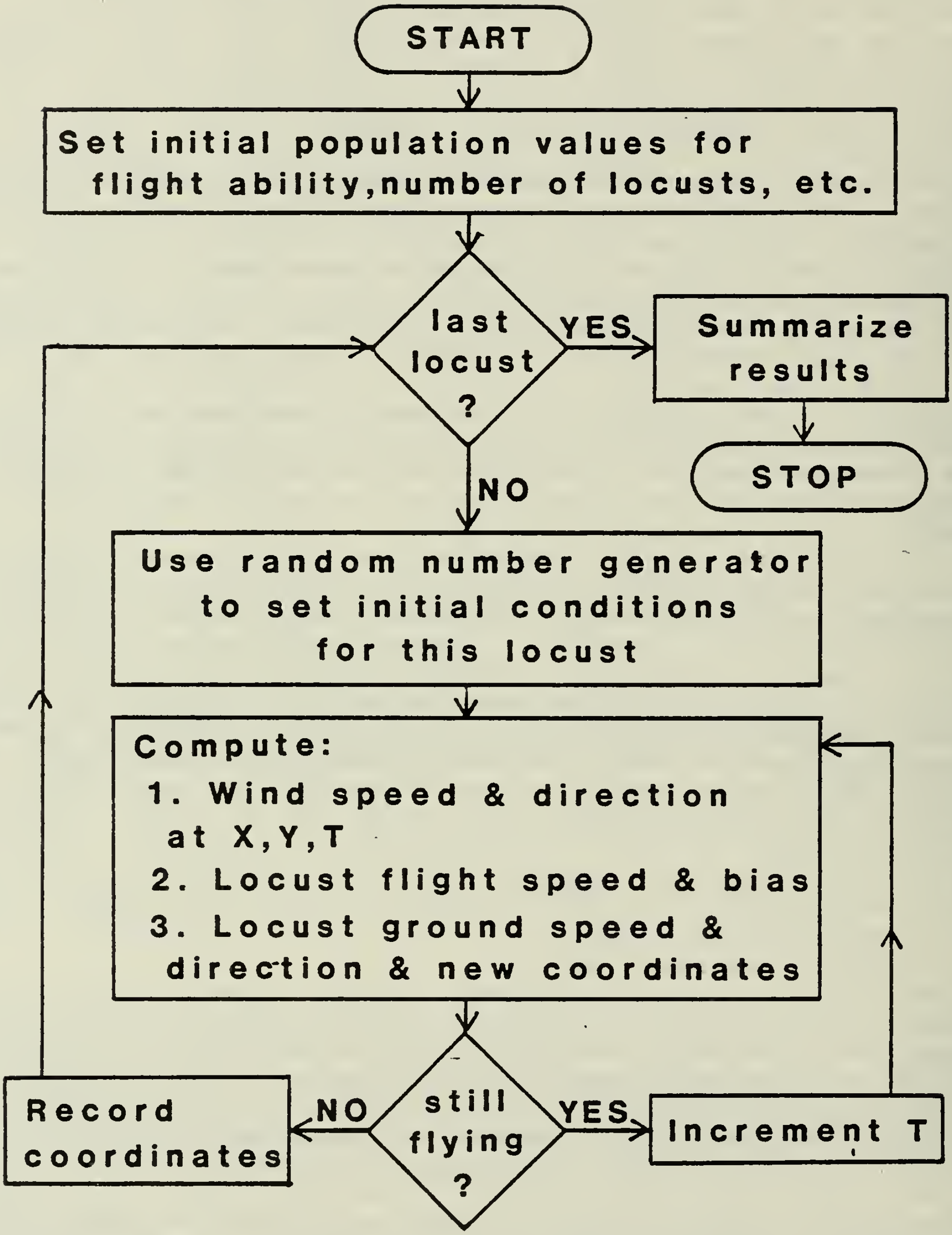

Figure 1

Flow diagram for a computer simulation model of desert locust migration (modified from Taylor, 1979).

In this case, he would set the initial conditions for the population at the beginning of his simulation and then one by one run through the individuals in his population using a random number generator to select the particular characteristics of the individual. Next he would compute wind speed and direction and the locust's flight speed, then its ground speed and direction, and finally its new coordinates. He would iterate through this process on a one-hour time step until that locust either died of exhaustion and fell into the ocean, or until it got to land and successfully landed. He would then record the coordinates of where that particular individual ended up and go back through the loop to start over again with his next locust.

This is one approach that would satisfy our notion of what an explanatory model should be. This sort of model tells you something about why a particular locust ended up at a particular place: because of the wind speed, its flight speed, and the various characterizations of the particular individual and the environment in which it found itself.

I have not worked with desert locusts nor very much with migration, but I would like to tell you about some work that I've done on two different systems here in Illinois with the help of many other people.

The first one is the alfalfa weevil. This is a beetle about a quarter of an inch long that feeds both as the adult and as the larva on the leaves of alfalfa plants. The larva is the stage that does most of the damage, and if you don't do something to control it, you might end up with alfalfa that has no leaves at all, although that's relatively rare these days because we know a lot more about this insect than we used to. One of the things that we have is biological control. There are a number of parasite species, some of which have moved themselves into this area and some of which we have intentionally imported to help combat the weevil. We also use insecticides whenever the number of larvae exceeds our published action threshold and we use cultural practices such as adjusting harvesting dates and maintaining plant vigor through fertilization and liming practices. Plant vigor is important because if we have X larvae on an alfalfa crop that's growing very slowly and is stunted, we would see a lot more damage than if we had that same number of larvae on a plant that's twice as large and growing vigorously.

One of the first steps in developing explanatory and predictive models is to develop a diagram of the life cycle of the insect pest. Figure 2 reflects the fact that adults (A_0) lay eggs which hatch, go through four larval instars (L_1 - L_4), a pupal stage, and the adult comes from that and following a feeding period (A_{f1}) goes into diapause, which is a resting, quiescent stage that allows it to pass the hot, dry part of the summer. In the late fall it returns to the field and does a bit more feeding (A_{f2}). After this feeding period is completed it begins to lay eggs. This normally takes place either very late fall or sometimes not until the next spring. To this we add the parasite Bathyplectes curculionis, which attacks the weevil larvae usually in the second instar. The larva continues to feed and grow, but from a parasitized fourth instar larva ($L4_p$) we don't get a pupa of the alfalfa weevil, but instead we get an emerging parasite which spins a cocoon (C). That cocoon may or may not go into the diapausing stage (D) and

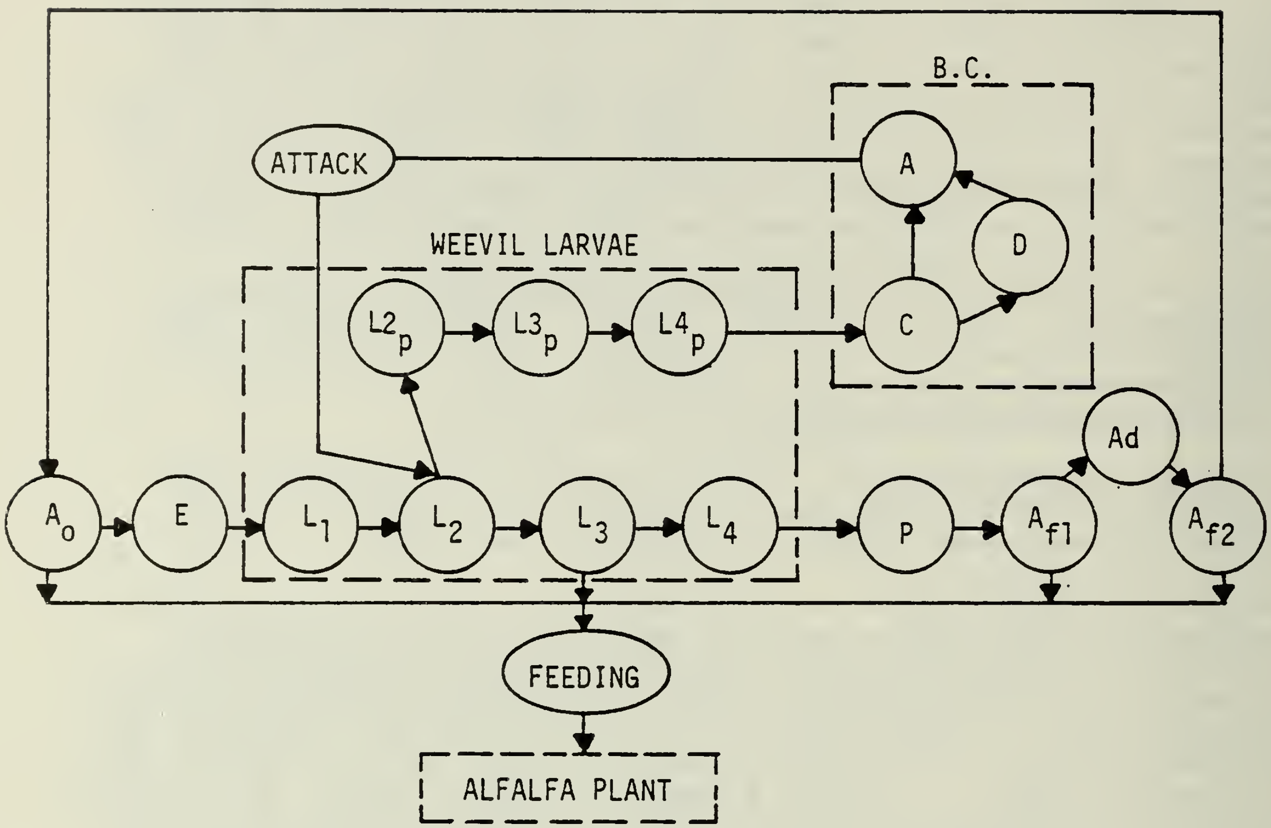

Figure 2

Structural diagram showing the components of the alfalfa weevil and B. curculionis life systems (from Ruesink, 1976).

spend the winter this way. We usually get one generation of the alfalfa weevil in a year and two generations of the parasite. In our system we also have a model of the alfalfa plant which is coupled to the insect model through the feeding process.

Having developed a diagram of this sort, it then comes to writing equations to describe the behavior of each of those component parts. As an example of the effects of weather or climate on the weevil, I show in Figure 3 the relationship between constant temperatures and developmental rate that was obtained for eggs in the laboratory. Perhaps 10 percent of those data points were gathered here in Illinois just to confirm that our population behaves more or less like others around the world. Some of those data points came from Egypt about 40 years ago, some came from Canada, some from California, and some from Europe.

This sort of temperature relationship is found for essentially every life stage of every insect species that has been studied, and temperature is by far the most important factor influencing the rate of aging in most insect species.

Oviposition, or egg laying, is a much more complicated process than aging. As Carl Barfield indicated for one of his moths, he knows that the age of the female moth has a good bit to do with how many eggs she will lay. If we look at a moth that's approaching her maximum age, she's not going to lay nearly as many eggs in a night as a moth that's young. Figure 4 shows the shape of the relationship for the alfalfa weevil. We also know, of course, that temperature is going to affect oviposition rate, and in the case of the alfalfa weevil, we have experimental data to indicate the shape of this curve too (Figure 4).

Another consideration is whether the female that is laying eggs is under any sort of nutritional stress. If she has had plenty to eat then she will lay eggs at the maximal rate, but if she is under severe food stress, she will stop laying eggs entirely. Since I have no data on the form of this relationship, a purely hypothetical relationship (Figure 4) was added to my model. I had found that without this, the model had some strange behavior under certain circumstances. An insect physiologist convinced me that something of this sort should be in the model, but I couldn't find any physiologist who was willing to do the experimentation for me at the time. I was in a hurry, so I made up a formula and, believe it or not, it corrected my predictions. I said "Great! I'll leave it in," and it's still there.

A third process that we want to consider is feeding rate. For the weevil I assume that the environmental conditions and the physiological state of the individual insect are going to dictate how much food it would "like" to eat in one day, if it could. But there may not be that much there, or it may be so distributed in the environment that it would take it all day to find it, so the availability of food may reduce the amount that is actually consumed. The amount that is desired I have modeled as a function of temperature, directly proportional to the developmental rate information that we have for each feeding stage, and then corrected by 2 minus the "food reserve function."

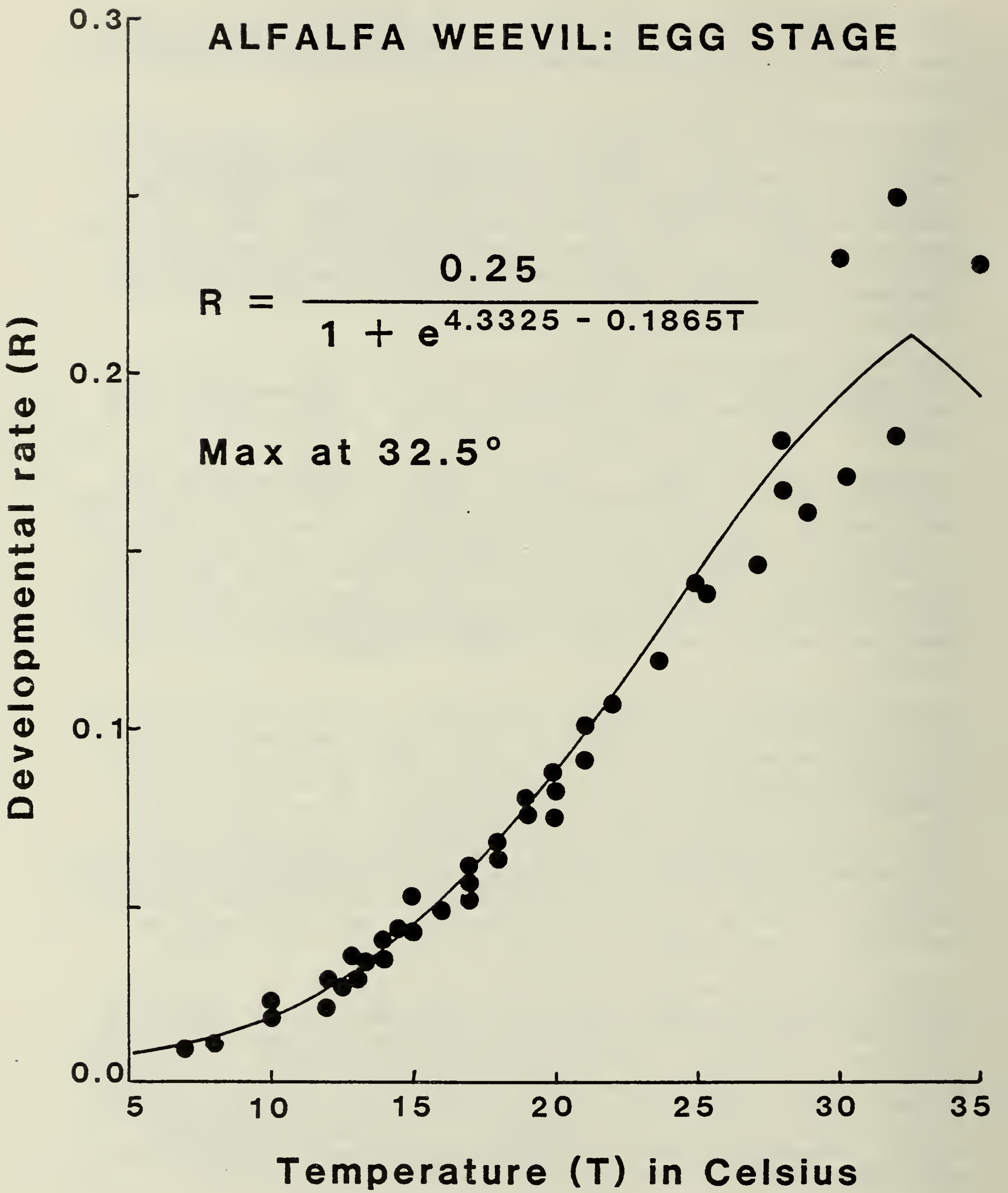

Figure 3

Effect of temperature on the developmental rate of alfalfa weevil eggs.

ALFALFA WEEVIL: OVIPOSITION

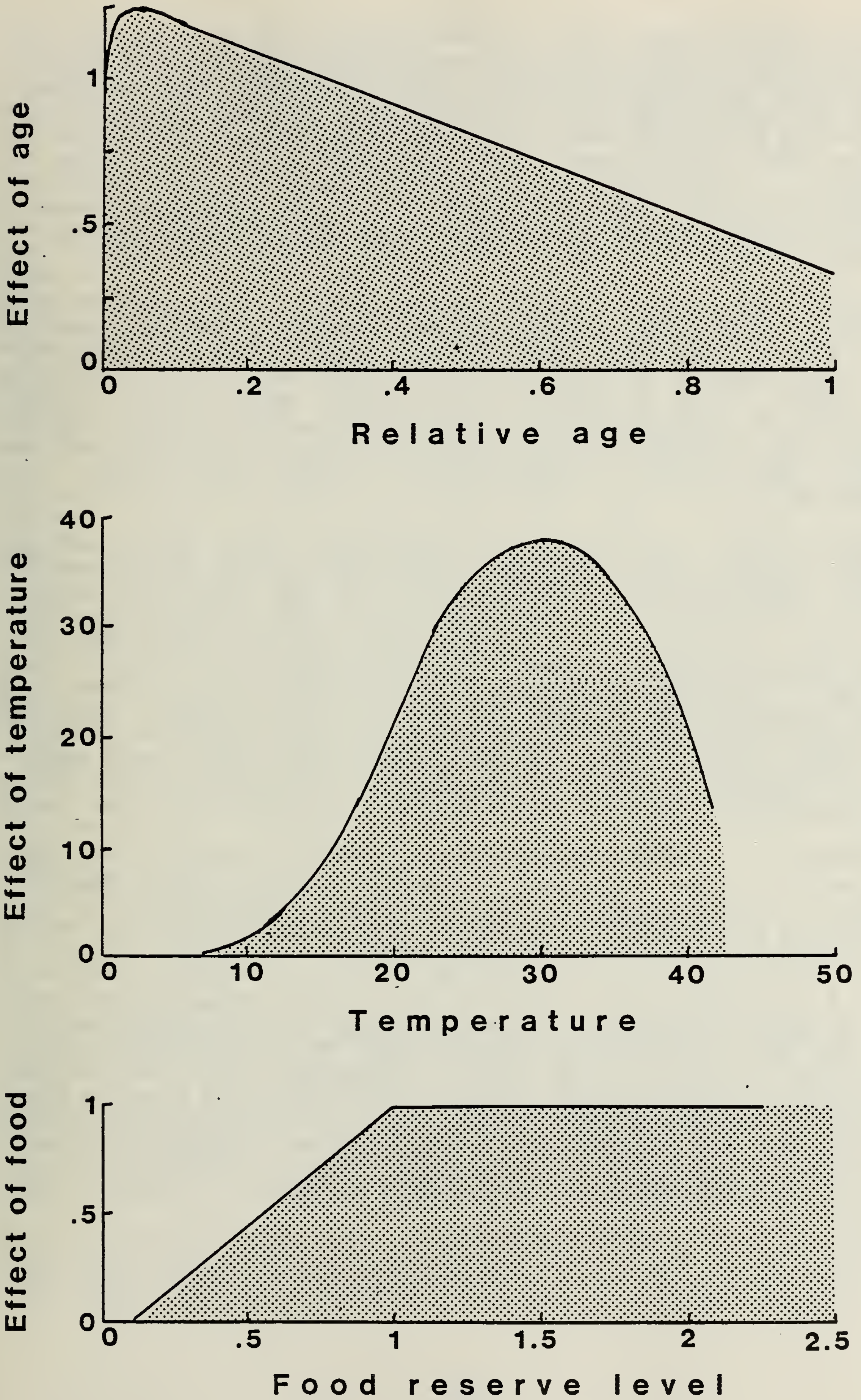

Figure 4

Effects of female age, temperature and food reserve level on daily oviposition rate in the alfalfa weevil.

The food reserve submodel says that there's going to be an increase in food reserve, body fat if you like, based on how much energy the insect takes in by feeding minus the amount it loses through normal respiration and laying eggs. If the food reserve level gets very, very low, then this insect might eat as much as twice its normal intake during any one day. If the food reserve level is up to normal, i.e., 1, then the 2 minus 1 term gives me a factor of 1. This is a way of adjusting the amount of food that an individual desires. Again, I emphasize that this is a hypothetical relationship. This is the part I wanted help with, but didn't get when developing this model.

I haven't shown you models for the other two of the five main parameters. I didn't say anything about movement because I'm assuming a closed system. This is one of those species that Carl says is easy to study. It doesn't have mass flights or any other form of significant long-range dispersal; the vast majority of the individuals in the population apparently move no more than 1/2 mile in their lifetime. I therefore assume that my study area is large enough to contain all the individuals of importance and the little bit of flux I have across the boundary equals out between immigration and emigration.

The fifth process is mortality, a very complicated process because there are so many different component factors in mortality. For the alfalfa weevil there is some basic underlying fundamental death rate, such that no matter how ideal the conditions are, there is a certain probability that some individuals are going to die at any given time. On top of that, there is mortality due to natural enemies. I have one parasite explicitly built into the model. Then there are predators: crickets feed on them, spiders feed on them, so do many other organisms. An alfalfa field is a jungle. If you were an insect living there, you'd fear for your life every minute. I did not model every mortality factor explicitly one by one; instead, I just lumped them all together in a way that describes the average mortality rate that we have observed in alfalfa fields.

Consequently, this model has some problems predicting numerical change over a long period of time. If the mortality rates in the model are all about 80 percent of what they should be, then for a two or three day forecast, I'm going to be very close to predicting the right levels of population, but for a long-range forecast I could be rather far off.

After I developed functional relationships for each of these processes for each of those 16 components, I put them together into a simulation model. The model that we built has been rather useful for predicting when an insect population will reach a certain stage of development. Since I'm assuming that I don't have migration to contend with, I can sample a given field and use that as my starting point and make a forecast for some time in the future and do quite well at saying when different events will take place. I can even do reasonably well for a short period of time at forecasting how many I'm going to have, but not for a long period of time.

Now I'd like to talk about a second insect, one that's quite different from the alfalfa weevil. Then I'll get back to some interpretation on each of the two. This second insect is the black cutworm. It's another one of Carl's noctuids, which as a caterpillar is the cutworm that feeds on our seedling corn and by cutting off the corn plants causes us all sorts of chaos.

As recently as 10 years ago, we knew almost nothing about predicting where this insect was going to show up. We knew that, on the average, something like 2 percent of the Illinois corn crop was damaged by this insect in any given year, but it would range from two or three years in a row in which almost nothing happened to years in which 10 percent or so of the fields were damaged. Some research that was begun here about 10 years ago identified eight factors as being important in indicating which fields were likely to be infested with black cutworm larvae. The most important factor was a previous history of cutworm damage. Fields that had problems in the past probably will have them again. This doesn't explain why, it just helps us point to where the problems will be. Previous year's crop of soybeans or corn, minimum tillage, or spring tillage, later planted corn, medium to heavy population of weeds prior to planting, adjacent permanent vegetation, poor field drainage altogether add up to the factors which tend to predispose a field to cutworm damage. The black cutworm does not overwinter in this area, as best we know, but flies in about April hunting for a place to lay its eggs. We haven't planted our corn yet in April, so what this insect appears to be doing is hunting for a field that has some weeds in it that are at just the right stage on which it can lay its eggs.

So if somebody has used minimum tillage, it may predispose his field to have some weeds. If he then has those weeds and the moths lay their eggs on them, and the larvae develop up to a certain size, then he comes through and plants his corn fairly late, those larvae will be large enough that they're now capable of cutting the corn. While they really don't like to eat corn, based on our laboratory studies, we do know that if you take the weeds out of the field and they don't have anything else to feed on, they'd rather eat corn than starve to death. That's why we get cutworm problems, we think, in most of our corn fields.

We have a very difficult problem, then, of forecasting where we're going to have problems other than we know that the above conditions predispose a field to be potentially attacked, but now the question is, will the moths actually come and fly into these fields at the time when we have weeds there, and if so, will they lay eggs there? Well, we do have a pheromone for this insect which attracts the males to a sticky trap that we hang around our field area, and in the traps we get all sorts of tiny insects that just happen to wander in there and look for a place to sit down, but we get very few other large moths except for the particular species that we're looking for. This allows us to say very precisely when the moths were flying, but like Carl's blacklight trap, it doesn't tell us very much about how many moths per square mile we've got flying around our neighborhood.

We use two distinct models in our black cutworm program. The one we usually use (Figure 5) begins with pheromone trap observations and information about temperature. Our cutworm development model will tell us when the larvae

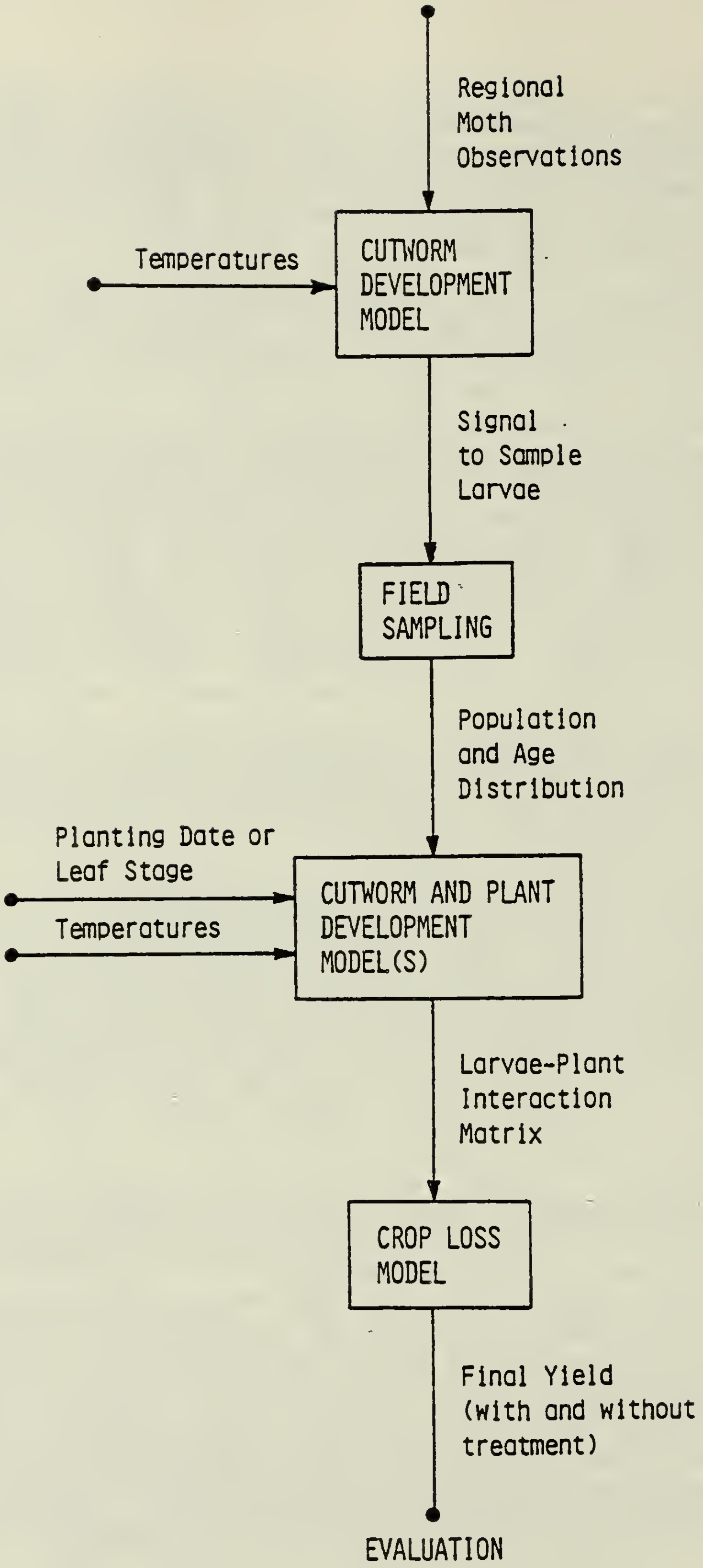

Figure 5

Fórecasting corn yield at the field level from planting date, temperature and black cutworm larval counts. Proper timing of larval counts is signalled by pheromone trap catches of adults.

would be large enough to cause damage. Therefore, we send the signal to the agricultural people who are interested in this sort of thing and say, "You'd better start looking on such and such a date. We don't know whether your field is going to have a problem or not, but that is the time that the larvae would be there and could start to cause problems. You'd better go out and look." So they go out and look, and then they tell the computer model how many they found and what the age distribution was. That information is used by a version of the developmental model that's connected with a corn plant growth model. They also need to tell the corn plant growth model when they planted the corn, or how big it was on some particular date. From this model we get an insect-plant interaction matrix which is passed to another calculation routine that we call our crop loss model. The final result is a statement about the impact that this population will have on corn yield with or without insecticide treatment.

You see that this approach requires a lot of sampling, and you may ask how I am going to use this to forecast whether I have damage or not in a large region. I say I'm not. But on a particular field, I can tell someone who's concerned when to go out and look for information which he then can put into the rest of our model: he can take it through himself to predict what the consequences of this population might be.

Some people say they'd like to do a little less looking if they could get away with it, so we have proposed another model (Figure 6), but we don't feel terribly confident that we're very good with this one. Here we begin with our adult catches in the pheromone traps and from them we infer an area population. We're trying to say, for example, if I catch five moths in a trap it means 10 moths per square mile or something of that sort. Then we go out and look at fields in the region and ask, "How many weeds do I have in these fields and how big are the weeds?" These observations are used to come up with an attractiveness rating. Area population density and field attractiveness together allow us to predict how many eggs are going to be laid in that field. We're not terribly confident - in fact, we're very uncertain - about this phase of our model at this point, but by putting it together we've indicated to ourselves and to other scientists where our weaknesses are, and we now have some feeling for what additional research would be necessary to build up this model to make it more reliable. We again use our plant development model, and from then on it's pretty much the same as what we had before.

Figure 7 represents my only attempt to do something special for this conference. Since this is a climate conference, and several people spoke about the possibility of having a warmer or a cooler future, I thought we might see what my alfalfa weevil model predicts should temperatures become warmer or cooler.

First, I ran the alfalfa weevil model for 10 years using actual observed temperature data from Nashville, Illinois, which is about 50 miles southeast of St. Louis, Missouri. That's one of our major study sites and I've used the model with Nashville temperatures many times for other purposes. With those Nashville temperatures, I predicted that the weevil population density

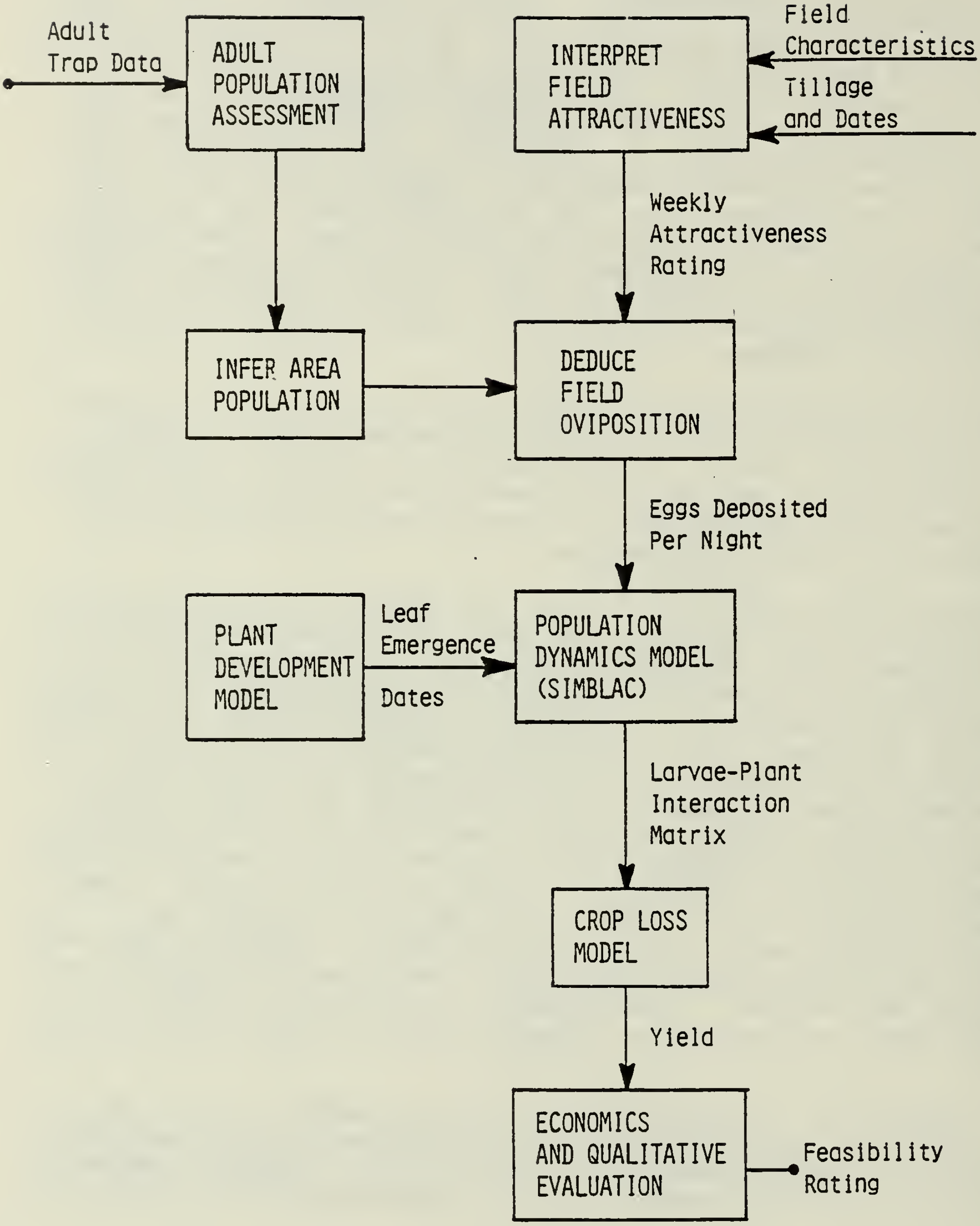

Figure 6

Forecasting corn yield at the field level from pheremone trap catches, field weediness and tillage practices.

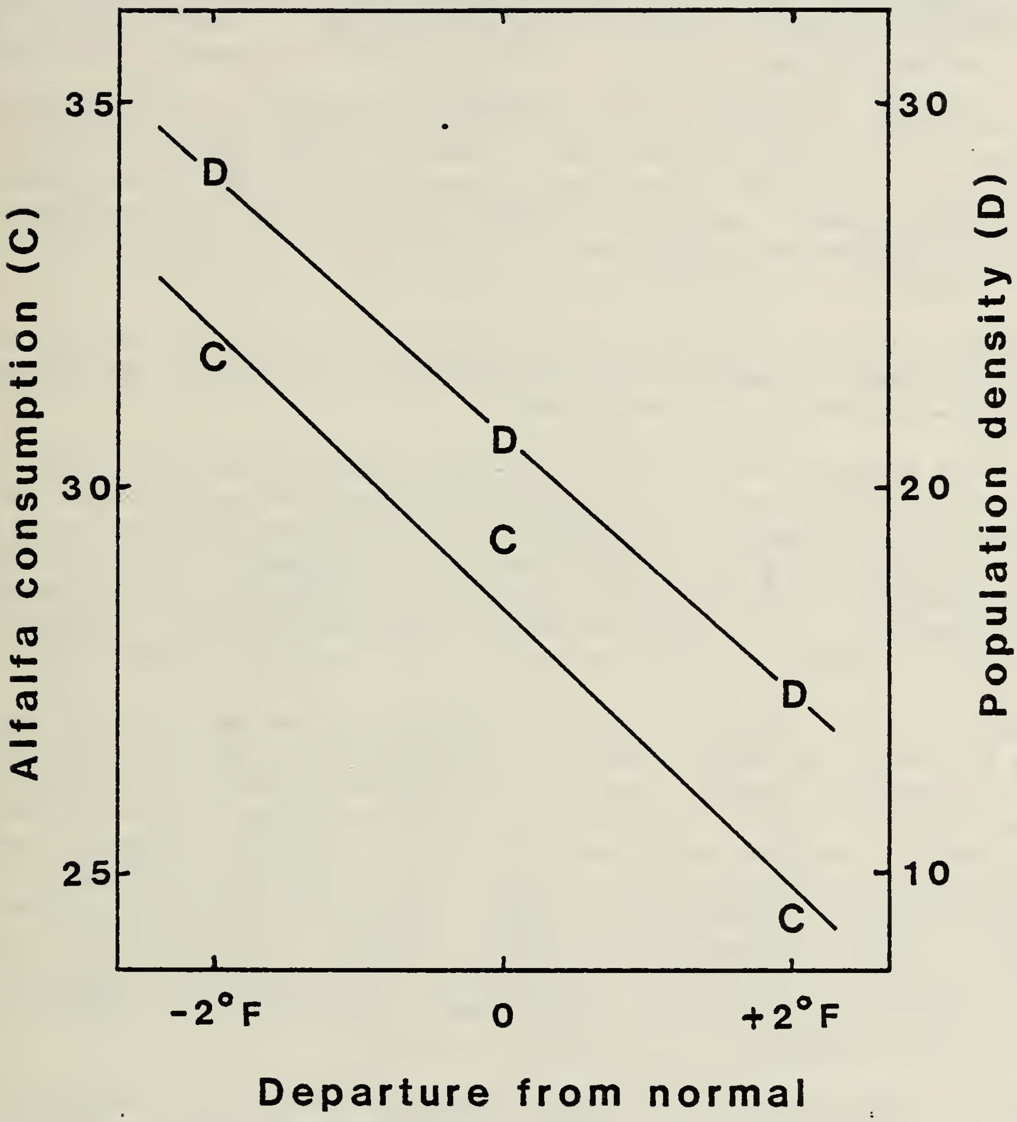

Figure 7

Predicting impact of climate change on alfalfa weevil numbers and their food consumption.

ought to reach somewhere around 22 adults per square meter and the consumption ought to be somewhere around 28 or 29 grams per square meter for the whole year. Then I used the model with that same set of temperature conditions, but added 2° Fahrenheit to the maximum and 2° Fahrenheit to the minimum for every single day of those 10 years of observations. It predicted that we would get fewer insects and correspondingly less consumption of alfalfa, and if we had cooler weather conditions we would get more weevils and correspondingly greater levels of consumption. I can't tell you exactly why it worked that way, because I didn't go into the model to see why.

I can think of several plausible explanations, but it probably relates to the synchrony of the crop and the insect. Under normal conditions, the first harvest comes right at a time when the weevil population is doing quite well. It's possible that if we have a slightly cooler season the synchrony of the weevil population and harvest would be sufficiently different to allow the weevil population to do better.

One interesting prediction that's not presented in Figure 7 is that the model forecasted that the production of alfalfa would be almost identical under all three sets of temperature conditions.

In closing I would like to say just a little about where I think we are in our efforts to have predictive capabilities and where we're going. I think that for black cutworm, alfalfa weevil and a few other species we're already pretty good at saying when certain events will happen in the life history of those organisms, when somebody should go out and sample, when he should treat if he needs to, etc. I think we need to work on this type of forecasting models for a number of other species that are important in our state.

Secondly, I think we need to work on forecasting how many insects are going to be present. The easiest way to be successful at that is to say that we're going to recommend sampling and ask the people to look at their own fields to see how many insects are there. We will then forecast ahead a few days or a few weeks to say how many insects to expect, but we're going to initialize it with some real observation in that field. Once we're successful at being able to do both of these things, then I feel it's reasonable to make an attempt to say where insects are going to show up. But that is a really tricky business, unless one is working with something like alfalfa weevil which stays in one place for a long time. Carl Barfield already told you about all his problems with his moths in Florida.

Finally, I believe that the ultimate purpose of any of our investigations is to make our results usable by people. That means, I think, making our models accessible, either through having a computer at some central location that the general public can access or by making the models themselves available perhaps as floppy discs that people can use on microcomputers in their home or in their office. That is our long range goal in insect forecasting and insect pest management.

REFERENCES

Freeman, G.H., 1977. A model relating numbers of dispersing insects to distance and time. J. Appl. Ecol. 14: 477-487.

Ruesink. W.G., 1976. Modeling of pest populations in the alfalfa ecosystem with special reference to the alfalfa weevil. Pages 80-89 IN R.L. Tummala et al, eds., Modeling for Pest Management. Michigan State University, E. Lansing, 247 pp.

Taylor, R.A.J., 1979. A simulation model of locust migratory behavior. J. Anim. Ecol. 48: 577-602.

CLIMATE AND PEST SYSTEMS IN ILLINOIS

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This talk is going to be different from those that preceded it today. It's not going to be talking about results so much as aspirations, aims, goals and progress in two projects that have been initiated here.

Insect pests are a major problem in Midwest agriculture. Understanding, predicting, managing these pests have obvious and significant benefits for this state. Also, many insects or pests that we experience in our agricultural fields do not and cannot overwinter in the state. Instead, each spring or early summer we find them migrating into the state, we believe from the south. The life cycle, migratory and local areal movement patterns, degree of outbreak and behavior of insect pests are closely related to weather patterns, but these relationships at the moment are insufficiently understood to be of predictive value. Also, for migrating insects weather factors have an overriding influence on all scales of movement, largely because the insects themselves fly much more slowly than the winds that carry them.

Today I'm going to be talking about two very closely linked projects that have been funded by the Department of Energy and Natural Resources. They have been established to investigate weather-insect relationships and input of this data into integrated pest management. I stand here as just a spokesman for the two groups.

The first project I want to talk about is referred to as the Pest and Weather program. We are going to be studying in detail migratory aphids or some varieties of migratory aphids, leaf hoppers and moths, some of which, in fact, are important as vectors of plant b---r? diseases. I should say too, I'm not an entomologist, so if I make bloopers entomologically speaking, forgive me and we can ask some of my cohorts later about what I really meant.

Four of the species that we are going to be considering are listed here in an interesting area of land in Illinois that has been treated for these insects in the past five years. There's no one year when all of the insects are very prominent. There seems to be no real pattern within any one insect with weather per se. All that we know is they are related closely somehow, but it is rather complex.

The ultimate goal of this project is the prediction of type, quantity and timing of insect pests migrating into Illinois. We have determined four objectives with which we will attack this problem. We have a group of meteorologists, entomologists and radar engineers who are going to be cooperating. The first problem or objective that we have is to try and determine source areas of the insect pests that we are going to be looking at. As Carl Barfield said earlier, this is quite a problem. We hope that we have some answers to that.

Secondly, we want to determine insect dispersal and movement in the atmosphere. We believe this is part of the answer to determining the migratory

patterns. Third, we want to identify local weather patterns and crop phenology that influences the migrating insects: what brings them to the particular area, what causes them to descend into the fields, things of that nature. Finally, we believe there are some answers in radar, again despite what Carl said. For a long time, we have observed on radar at the State Water Survey what have been called clear air echoes. These signatures have really been ascribed to turbulence in the atmosphere under clear conditions, but may also be related to insect activity or presence.

The procedures that we are going to use in attacking each of these four objectives are as follows: First of all, to try and detect the origin of insects that migrate into Illinois, we are going to be catching insects here with various types of traps in fields around the state and we will try to identify their origin according to information that we have gathered from insects collected in what we suspect to be source regions. The first is a genetic approach, genetic marking or fingerprinting. We have made collections in the south of the state at a number of points to this stage. We intend to make more. We have determined already that we can genetically identify source regions for insects as long as we know the species of host plant that they have been feeding on. We can identify their source region at least on a partial state basis, genetically.

The second approach. We don't know if the insects that migrate into the state make one flight from source to sink, as it were, in our fields or whether they make several hops along the way. In approaching this problem we're going to look at their energy reserves. Experiments have been conducted looking at a number of facets. We have used one of the aphid species, Armetis--?, to date, and we have looked at a number of factors that may be influencing the energy status of the insect so that then when we collect insects in the field, we'll be able to look at these factors and try to determine what it means, what distance the insect has traveled according to these particular inferences. We have looked at the effect of age on the energy reserves in aphids and have found that younger insects have more energy reserves, or higher energy reserves. We have considered energy reserves with respect to the reproductive stage and have found that it seems to be noninfluential.

If we look at insects at the same stage of growth at different times in the season, in other words, insects that have hatched or reached that stage early or later in the season, we see that the later in the season the insect has reached a particular stage, the more energy reserve it has at that stage. We have also been doing tests with insects attached to fine fibers in wind tunnels making them fly for specified lengths of time. Those experiments are still in progress. Energy levels have not yet been determined. We also intend to look at starvation or lack of food and see what effect that has on energy reserves. We hope that by pulling all these things together, we will be able to use this information with the status of insects that we catch here next season to determine how far they've come on their latest flight.

The third aspect in determining the source of insects coming into the state will be meteorological, using trajectory backtracking. We're going to back-

track from Illinois using weather information and using information that we can discern about location of the insects in the air stream to try and determine the most likely source regions. There are a number of problems, however, one of which is illustrated here. I guess this is the sort of thing Carl was referring to when he said there are lots of problems in determining flight paths. We have used old data, meteorological and insect data, and we have developed back trajectories from Champaign when we have had known influxes of aphids, and if we use as, in this case, winds at the surface or winds at 850 milibars, we in fact find two very different trajectories. In fact, it's something like 750 kilometers' difference between the source regions in this instance. We have done this, unfortunately, only for summer data; we have to look also at spring data, which we believe to be the time when most migration takes place, but we expect the problem to be just as severe.

Because of this we must determine the height in the atmosphere at which the insects are traveling. To do that we are going to look at samplings of insects from aircraft. This is part and parcel of our second objective, which is to try and determine the distribution of the insects in the atmosphere, both in time and space. We are developing at the moment a sampling trap to be attached to an aircraft which we will fly and we will take samples when we believe, from radar data, that we have high influxes of insects. These insects will then be checked for energy status, for source location with genetic fingerprinting, and at this point we'll also do backtracking to check on the source location with the genetic data.

We have already undertaken a number of radar experiments to see if we can discern insects in the atmosphere. We did most of this work in the spring of this year using moths, leafhoppers and aphids. We used two radars that we have here, one at the State Water Survey, a Dopler 10 centimeter and 5 centimeter radar of the Ch--?, and the other a 3-centimeter tracking radar at the Natural History Survey. We found that at distances at least of about 2 kilometers we could identify one moth with the ch--?. We could certainly track one moth to one kilometer with the GPG; that's a tracking radar. We could also identify what seems to be a wing beat frequency, which may give a clue to determining species; that's still to be decided.

In addition, we have an acoustic sounder which will help give us some information about the planetary boundary layer of the atmosphere or the top of it, where we believe the insects are traveling. In addition, locally we will have vertical monitoring systems, systems of traps, sticky traps, in the main, that will catch or sample the insects coming to them so that we can try and determine landing rates and rates of landing immigrants versus landing local insects. We have a problem here: we want to identify those insects that are coming in from long distance compared to those that are just interfield and within-field moving.

On a state level, we also have a set of meteorological sites, the Illinois climate network sites, which will be equiped with rotational traps that have a time resolution of three hours. These will be traps that rotate exposing one trapping source material every three hours. It will be left open for three hours and then will rotate and another one will be exposed. With these

we hope to be able to map, plot, the influxes of insects coming into the state and their movement pattern. Also, the sites will be used for determing the related meteorological information.

Locally, we will also have a very detailed measurement site for both meteorology and entomology. This will be a site in a soybean field where we will be casting most of our attention on incoming aphids. The reason we will be using the soybean field is because the aphids don't colonize in the soybean field so what we find there will be transient insects. But we will have detailed micrometeorological information, hydrologic information, be able to determine crop status, we'll also be keeping a close watch on crop phenology and insect activity. There will be a variety of insect traps there, some of which will be bulk samplers, suction traps, from which we cannot really get aerial densities of insects, and some of which will be sticky traps which are nonattractant or nonrepellent to insects we believe, and we'll use these to get the densities. The bulk traps will be used to sample when we have lower densities.

In addition, we have some special experiments, some of which have already been initiated this year. One experiment which is going on today, right now, and will not finish for another about two hours is to look at disposal of insects within a field. This is in this same soybean field. We have released some aphids, again, Armetis--?, about 5,000 of them tagged with fluorescent dyes. We released them from a grid network in the field around 6:30 this morning and we are waiting for 12 hours, during which time we are making half hour checks of upwind and downwind nets so that we can try and determine if these insects move with or against the wind. Our preliminary information indicates that there are some species of aphids which move into the wind, some which move with the wind. However, consistent with Carl Barfield's statements, our first experiment, which was done last week, gave us insufficient sample at the end. We just collected a few insects in the net, not sufficient for statistical analysis. So we're doing it again with a slightly different format.

So much for the pests and weather. I've very hastily skirted through what is a very large project and I'll move now to the second project. The first one is rather a scientific experiment where we are looking for new information. This second one is a more applied project, which will take information such as we hope to generate with the pest and weather project and make it available to farmers in the way of beneficial information. At the moment, they are using information gathered from the literature, primarily, and weather data that are available, and developing that along with the pest model, the phenology model to provide information to farmers on damage dates, or dates in which they should check their fields. I'm not involved with this project, but I hope I can handle it sufficiently.

The goals of the project are three: essentially they want to merge current technology, including computer technology, with real-time information. They want to have a model which will use current information obtained over the telephone, use that model to generate dates and information which can then be transmitted directly to farmers and other users who call a central computer or who call the computer and take the model and or data onto their

computer and work it locally. Secondly, they want to adapt and develop pest models--these are phenology-based models--improve them and develop them for more insects. And they also want to provide climatic probabilities using past data, conditional probabilities and pest information.

If we look at the project schematically, this is the way they are approaching the problem. First of all, there can be current data, data that come into them over the telephone climatic data, pest data and crop data. Also they can use historic data; these will be in the form of conditional probabilities which can be input into the pest model. I've got their pest models, but I find now it is a generalized model which is updated with different base information for the different insects involved. The output from the model, along with conditional probabilities, is combined to give a user a set of products which can be relayed by different ways to state and federal agencies or to agricultural users, extension advisers and so on.

The insect pests for which they are developing this model are quite varied. Three are related to corn. The date listed after each insect pest is the date in which it has been or will be implemented into the model. At the moment, most of the testing has been done with the black cutworm, some also with the alfalfa weevil. As you can see they are also targeting soybeans, alfalfa and are now expanding into trees and forests.

All of these are at least moderate insect pests in the state. The model uses 20 areas within Illinois, or at least they have divided the counties of Illinois into 20 areas, and you can get specific information for each of these areas on the pests in which you are interested. Going back to that schematic flow chart, first of all the historic data base, I think they're using 80 years of data and they are going to develop conditional probabilities for periods of four months to many years. They are going to examine a number of past situations where they have information to tune the model, and in general it will be used for further development of the model.

The real problem for the user is that you must have current information. This is one of the major problems in the project. You must have, first of all, the sources for the information and secondly a device computer system, that can handle it and be free for users to call. In real time data, the project will have the capability of collecting from certain stations in or near the state daily, but basically it will be looked at on a series of days or in periods up to four months. This will be used to provide a current climatic and pest description for the state of Illinois for each of these 20 districts.

There will be five sources for the climate data or weather data. First of all, the national weather service first-order ally stations around the state are in or near the state, six within the state, three nearby. There is also a set of what are termed "Agnet"--? or agricultural weather stations established by the National Weather Service that provide daily data. I have 24 here (in fact that should read 15 since it incorporates these 9). Both of those sets of stations can provide real time or near real time data already. Under the CAPS project there will be 30 additional stations implemented with touch tone phones where cooperative observers will key in climate information

on a daily basis, first thing in the morning. That will increase the network.

Additionally, there are nine stations on the automated field network of the National Weather Service that is being established. Nine "ROSSA"--? stations as they are referred to, which will come on line some time at the end of this year, I believe. Their data will also be incorporated into the data of CAPS. And finally, a not real time but an expanded-type data set with more information that may be useful like soil moisture, soil temperature and solar radiation and wind information is the Illinois Climate Network, currently 7 stations around the state soon to become 13 when we receive some more equipment. In addition, they will be receiving pest and crop information from people in the field, field observers and extension officers. To get some idea of the spatial pattern of these stations around the state, the first-order National Weather Stations are dotted there in blue; they currently get the information from those. The Midwest Agricultural Weather Stations, 15 additional stations that give them a reasonable pattern of stations. In fact, it gives them a base of one station per district, in the 20 districts that they have in the state. That is the network from which they can get data at the moment.

Shortly, they are planning to implement these 30 additional stations and hopefully the ROSSA--? stations will also come on line. We can see at that point they are starting to get quite a reasonable spatial pattern of necessary weather information. And then finally, the supplementary stations with the special data, the Illinois Climate Network. By the time they have all of this information in there they should be able to get good average data for each of these 20 regions.

A little bit about the model itself. First of all, the basis for the model itself is that they believe that there is a strong dependence of insect development upon weather. In fact weather conditions, particularly temperature, provide the greatest explanation to insect development, at least the insects they are considering. The basis of operation of the model is that it takes real time weather data up to the date of computation and computes the current climate situation where the insects have been exposed. From that, using phenology information in the model, the current life stage of the insect is determined or estimated. They then develop a prediction of when farmers should go into the field to check insect status, or when they believe damage would be initiated or become severe using conditional probability data.

The final thing is to predict earliest and average dates of damage or needing to check, so the final statement there is the sort of information that the farmer or extension person would get. The inputs needed in the model are essentially a starting date, what Bill Ruesink was talking about. He needs some information to start him at some stage in the life cycle of the insect. Once they have that, they can then progress with their model, or in this case with this model, to determine or estimate what the insect stage is at the time. They need a base temperature. Since this is worked primarily on temperatures, they used degree days. They have different base temperatures for each of the different insects and sometimes different base temperatures for

different stages in the insect life cycle. They then have some threshhold of accumulated degree days, a stage, a threshhold accumulation, at which they would expect damage or at which time they would expect a farmer to have to go into the field.

The output from the model is essentially a set of dates for whichever area and whichever insect species you are interested in. It's essentially a phenology by weather probability matrix. A farmer or user will pick from that small matrix of nine values, either one value or one of two which are usually provided to him. A second option is to have predicted heating units or accumulated heating units for a particular date in which the user is interested so he might want to have an estimate of how many heating units he will have six days beyond the current date, and that is a second option available in the model.

Schematically it is something like this: from our starting date, heating units and I have a straight line here. Of course, it's not going to be straight. As we've seen this morning, it will have a lot of noise, day-to-day noise, but I've represented it as a straight line. The current climate for the insect development to that stage will be represented by the climate or weather data to that point in time, so at the time of the user contacting the model we will have this climate information upon which we will be basing our predictions. Using conditional probabilities, historical data, extrapolations will be made from the "now" point into the future to a threshhold level, in which case a series of dates - I've listed them here as low, average and high, essentially encompasses about 90 to 93 percent probability of this threshold being reached according to the past data. Or in the second option, if the user wishes to make his own interpretation and wishes to nominate a date of interest the prediction will be what accumulation of heating units will have occurred to that point in time - again, with a 93 percent probability of inclusion.

To get some idea of the base information that is put into the model - this is largely from Bill Ruesink who spoke earlier - we have here on the left degree days, accumulating heating units. We have across the top different insect pests, and we have Bill's understanding of the change in insect life stage. Wherever I have put a D on these it refers to the damaging stage or most damaging stage of the insects. C refers to the point at which we can effectively control them. You'll notice this one, best spray date. In the case of the alfalfa weevil, prior to harvest there is a continuing problem. You have to go into the field every 350 or so accumulated heating degree days and have another check.

For another set of insects, this gives some idea of the threshold values that are applied in the model. We talked about black cutworm, its most damaging stage being in the third to fourth instar period. Moth flight does its damage at periods when we cannot effectively control it; we have to control it at some other time. So we are looking to find predictions for these best control periods.

At the moment, the products that are produced by this model and available to users come from an IBM personal computer. The extension offices around the

state are getting or already have these computers and they are able to tap in and get this information.

This is for the alfalfa weevil for this year. Current date, the "now" date back on those earlier plots is April 19. These are the 20 districts around the state. We can see here the early date in which you should start checking your field and the average date, given average heating conditions, temperature accumulation conditions, for each of these districts. That's a case where the farmer should go into the field and do some checking. In the second one, which is for the black cutworm, this being for third of May, this is an indication of when to expect damage. The early date is in the third instar stage and the average date is fourth instar. We would definitely expect cutting here; this would be a stage of early cutting within each of these districts. This information as I've indicated is continually updated, or at least on a daily basis.

The accomplishments of the CAPS program are this year to date: First of all, they have purchased, installed and developed a lot of the software for a Eltoss---? computer, a stand-alone, eight-user computer, which will be a storage and retrieval system for climate and pest information. They have already begun to store the climate and pest information as data bases. They have begun the development stage of this enhanced climate information network with the touch phones. They have been waiting on the National Weather Service to establish their Rossan---? sites before they go ahead, but that stage has been reached now and I think they are in the purchase stage for equipment. They have developed a generalized phenology pest model and they have also determined appropriate heating degree units to insert into that model at this point for seven insect pests, and they have another seven to go. They have initiated public use of this project with the black cutworm moth.

That's a quick outline of two large and fairly detailed projects being handled by a number of people. The pest and weather project has the opportunity for numerous scientific benefits in the understanding of pests and their interaction with weather, particularly in the area of insect movement. We believe that the link between these two projects is that the pest and weather project will provide much improved information for the CAPS project, so that they can improve their model and expand it to handle other insects. It is believed that these two projects combined will provide increased benefits to agricultural users in the state.

GLOBAL IMPACTS OF CO_2 CHANGES IN THE ATMOSPHERE

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The organizers and the speakers have led us nicely from physical to biological background for today's program. To help sew some of these pieces together, let us first review the carbon cycle itself (see Figure 1), and global changes in CO_2 and climate. The extra carbon dioxide in the atmosphere will be related to historic inputs from the organic matter of the biosphere, mostly plant and humus carbon, in addition to those from the much-discussed coal, gas and oil. Then we need to think about some approaches to and reasons for anticipating several kinds of ecological impacts of climatic change. Certain effects will be related to the geography of temperature and the programming of growth studied from experiments under controlled conditions. Others concern water and energy balances and even wind.

It is for you, the audience, and perhaps officials in agencies like Energy and Natural Resources, and for our elected leaders, to use the pieces of scientific information which we organize in meetings like this. Despite uncertainties, your own conclusions about whether or when to start a kind of planning function may well shape our future.

I appreciate the help and interest of many other people from Oak Ridge and elsewhere, and our supporting agencies (NSF, DOE) in making these connections possible. My selection of results, and personal judgments on their implications for likely climatic change, in no sense reflect any official "party line."

THE GLOBAL CARBON CYCLE

We may expect some continued uptrend in the carbon dioxide of the atmosphere unless energy and land use trends change radically. The release of CO_2 comes partly from burning of organic matter that had been laid down hundreds of millions of years ago. Illinois' coal and other fossil fuels were buried with other carbon residues in a great mass of sediments. Over 100 billion tons of it have been released to the atmosphere since 1860, but at generally accelerating rates (recently nearly 5 billion metric tons per year, as elemental carbon).

Soon after the International Geophysical Year (1957), the exchanges of atmospheric carbon dioxide with the upper, intermediate and deep water layers of the ocean were inferred to account for about half of the released CO_2 which no longer remained in the air. Less is known about the organic matter, both live and dead, within the ocean itself, but organic remains sinking through those layers delay the return of CO_2 to the air. There's also more emphasis recently on relations between the polar ocean, the atmosphere, and the intermediate and deep parts of the more stratified ocean waters.

Less clear has been the exchange between the atmosphere and land life in regulating the global picture, despite long interest. Even since some of us began synthesizing what was known earlier (Olson 1970; SCEP 1970; Baes et al, 1976, 1977), there have been several interesting developments. One is the Swiss and French evidence from Greenland ice cores: that the atmospheric CO_2 content of air trapped in that ice 100 or 150 years ago was lower than people had generally been assuming: about 280 parts per million by volume, compared with around 340 ppm now - an increase of nearly 18 percent.

The best explanation of finding such a large change is the above-mentioned input to the atmospheric carbon dioxide from the biosphere itself (Olson et al 1978). There are considerable differences, several-fold differences perhaps, in estimates of how much of the excess CO_2 to the atmosphere in recent decades has been coming from organic matter of plants and soils. To reduce uncertainties, we must resolve several dynamic processes of chemical reactions suggested in Figure 1a.

Annual cycles of CO_2 are clearly related to the rapidly changing plant materials, like each year's crop of leaves and residues. The more slowly exchanging pools of wood and soil humus had been stockpiling CO_2 from the atmosphere until inputs became (formerly) nearly equal to outputs of CO_2 by respiration and decay. "Gross primary production" means the rate of organic carbon absorbed by photosynthesis, well over 100 billion tons a year worldwide. Some of that photosynthetically-fixed organic carbon is very promptly released, by the respiration of the green plants. Respiration is a kind of tax, either income tax (on their metabolic rate) or property tax (on stored accumulations) on the plants for being able to keep in business (Olson 1964). It recycles 1/3 to 2/3 of the annually fixed CO_2. The "take home pay" of usable plant material, or net primary production, is stored in the short-lived materials plus longer-lived organic materials; the latter products are also returned to the atmosphere but a bit more slowly: over decades or centuries. A combination of respiration of animals, microorganisms and other decomposers recycles over 50 billion tons of carbon annually. Several billion tons a year of carbon are recycled even more directly via burning by fires, grass fires, forest fires, occasionally peat fires as well. Much smaller deposits in the earth's saving account of carbon go to the sediments, creating the vast resources of peat, coal, oil and gas, plus carbon dispersed in shales, over the millions of years of geologic time.

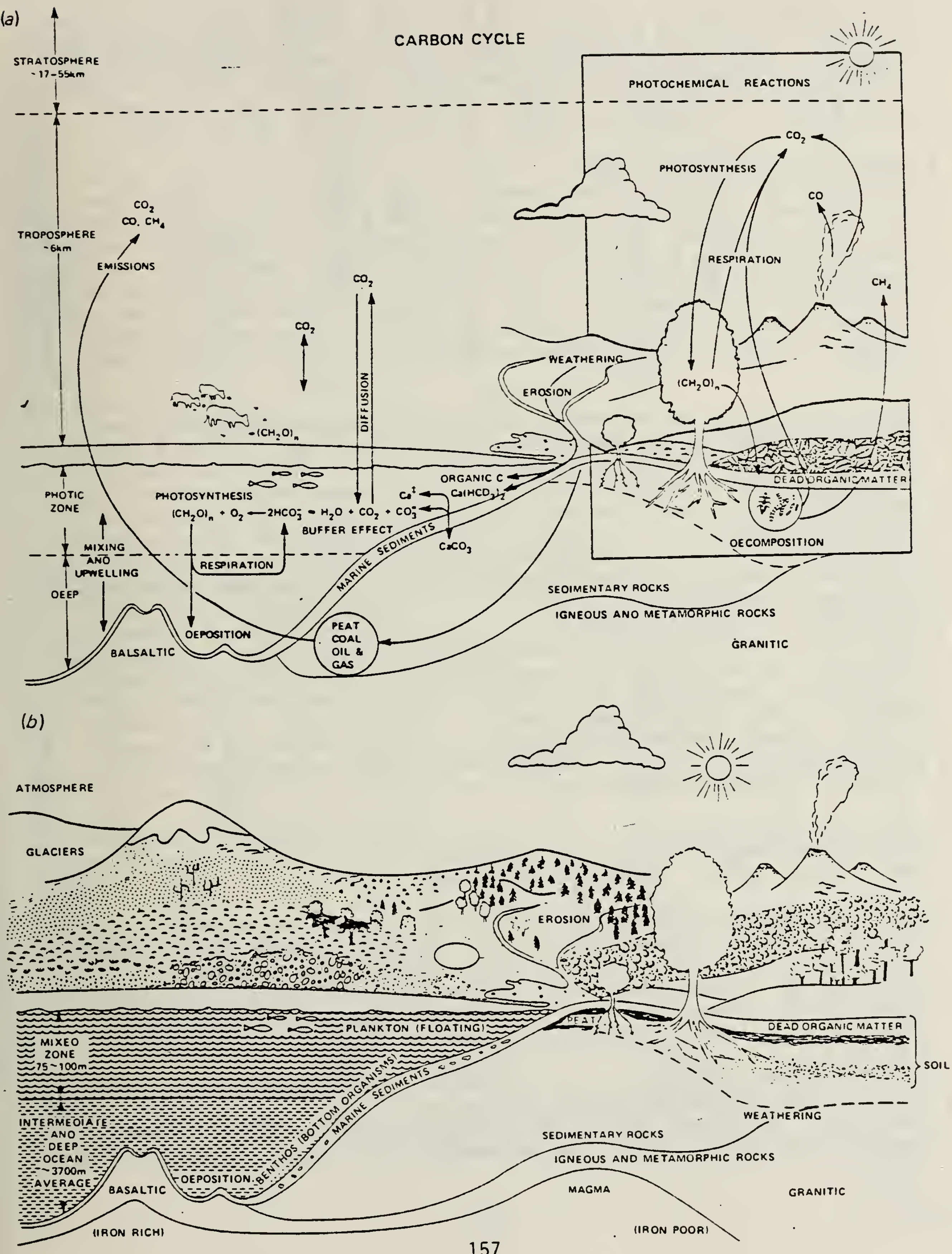
But is this exchange really close to a quantitative balance, as textbooks have told us for over 100 years? How near equality is essential for maintaining the world in a manner that is habitable for life? Some of my good friends and I have disagreed about just how much nonfossil CO_2 is being added, besides the release from fossil fuel. I can't cover all the arguments but will indicate the progress completed quite recently (Olson 1981, 1982; Olson et al 1978, 1983).

We have reviewed the locations of the different biological systems, ecosystems or landscapes of the world (Olson and Watts 1982). Several people this morning have already asked about the posted map which you can look at during the coffee break. Our report to the Department of Energy describing that map will soon be reprinted for those who are particularly interested

Figure 1. World-views of the carbon cycle. In (a) the specialized research on subsystems of atmospheric chemistry (upper right), plant physiology, and soil microbiology and zoology explain part of the balance of carbon dioxide fixation to support life on earth: by photosynthetic income of organic carbon, and by its return to the atmosphere by respiration (and also fires, not shown). In the upper, sunlit water layers of lakes and oceans organic matter is also fixed from dissolved carbon dioxide in the form of bicarbonate ions, and returned to these forms by prompt respiration or by delayed decay of deposited detritus, or by long-delayed burning of fossil fuels. In (b) is another broader, complementary view of the whole world ecosystem, with its diverse resource regions, conditioned by varying climates which are created by solar energy, atmospheric circulation, and ocean redistribution of heat and water. Human intervention on the landscape's many uses, as well as a prior history of natural climatic changes, have been decreasing the organic carbon in most forms of live vegetation and humus, thereby adding to the excess CO_2 that has been increasing rapidly through burning of fossil carbon for our industry. The main questions for broader inquiry are: How are the small- and large-scale (long-term geochemical) cycles of CO_2 and carbon related to those of other elements? How rapidly could atmospheric CO_2 increase under different assumptions about future use of fuel and land? For a given assumed future of CO_2 (and other gases, and of energy balance for altered reflection and evaporation of the landscape and water bodies), how rapidly, and where could the climate change most? e.g., with one or two doublings of CO_2? What kinds of research are required to clarify the impacts of more or less wild landscapes, as well as on managed farms, and forests, and water bodies? How can people take advantage of the present incomplete knowledge and foresight, for contingency planning of response to diverse weather and climate changes, without presuming to wait for complete answers to all of the preceding questions? (Jerry S. Olson after Larry D. Voorhees)

Figure 1

ORNL-DWG 84-1457



(Olson, Watts and Allison 1983). The map itself is also available in a book (Clark 1982) published by Oxford University Press called Carbon Dioxide Review 1982. Chapters of that book, with rebuttals and critiques, review the information and perspectives that some authors had on many aspects of carbon cycling and climate besides sources and sinks of CO_2. A series of meetings going on this year and next year will update that general status.

Some of the accelerated release of CO_2 to the atmosphere is offset by rebuilding or restoring of organic matter in new forests where some of the old ones were cut down and burned down. There's also been a shift in burning. The "Smoky Bear" syndrome (of rather zealous fire protection) has increased the storage of live and litter fuels, at least temporarily. But in some places such accumulations help to increase burning again whenever we do get very hot or dry weather. If the dry climate, in the scenario that Will Kellogg advocated, becomes even more typical, this suggests we will have a feedback - from increased burning releasing CO_2 even more rapidly in the future.

The various categories of landscape, which are pictured in Figure 1b and described briefly on the legend of our colored world map, have each stored an amount of carbon which is proportional on the one hand to the area of each ecological system and on the other to its carbon amount-per-unit area. Multiplying carbon amount-per-unit area of land times land area occupied gives the area of the box in Figure 2, proportional to the carbon stored in each kind of living plant organic matter. The "woods" (various closed forests and somewhat interrupted forests and woodlands) have most of the earth's live carbon (left-hand part of Figure 2). There is relatively less, much less, carbon stored in other kinds of live ecological systems: either the artificial cropped ones (which have some woody crop plants); the grasslands and shrubs; polar and alpine or desert systems. Many wetlands are really a mixture of woody (swamp) and nonwoody vegetation and have a kind of compromise or intermediate general level of carbon storage. Many of these wetland systems have stored a great deal of carbon as peat or muck soils. Tom Armentano, who is here from Butler University, has just completed a specialized study focusing on organic soils and their storage of carbon.

We already have impacts on a global scale onto the biosphere following directly from human activities - even without waiting for the climate to change and add some indirect impacts due to climate.

Census records of the United States quantify the familiar geographic shifts in farm clearing. Between 1860 and 1920, cropland expanded rapidly, especially here in the Middle West (see Figure 3). Then, even after 1920, clearing continued further West. In the eastern USA, cropland clearing stopped. In many parts, formerly cropped land grew back into wood lots in recent years, e.g., to what I've called the "suburban forests" of New England.

The Duke University historian, John Richards, helped us make a first approximation estimating the balance of net clearing of cropped land for the rest of the world. Even though not all of that cropland is from formerly forested woods of much higher biomass, the net shift has been to more open land. Most

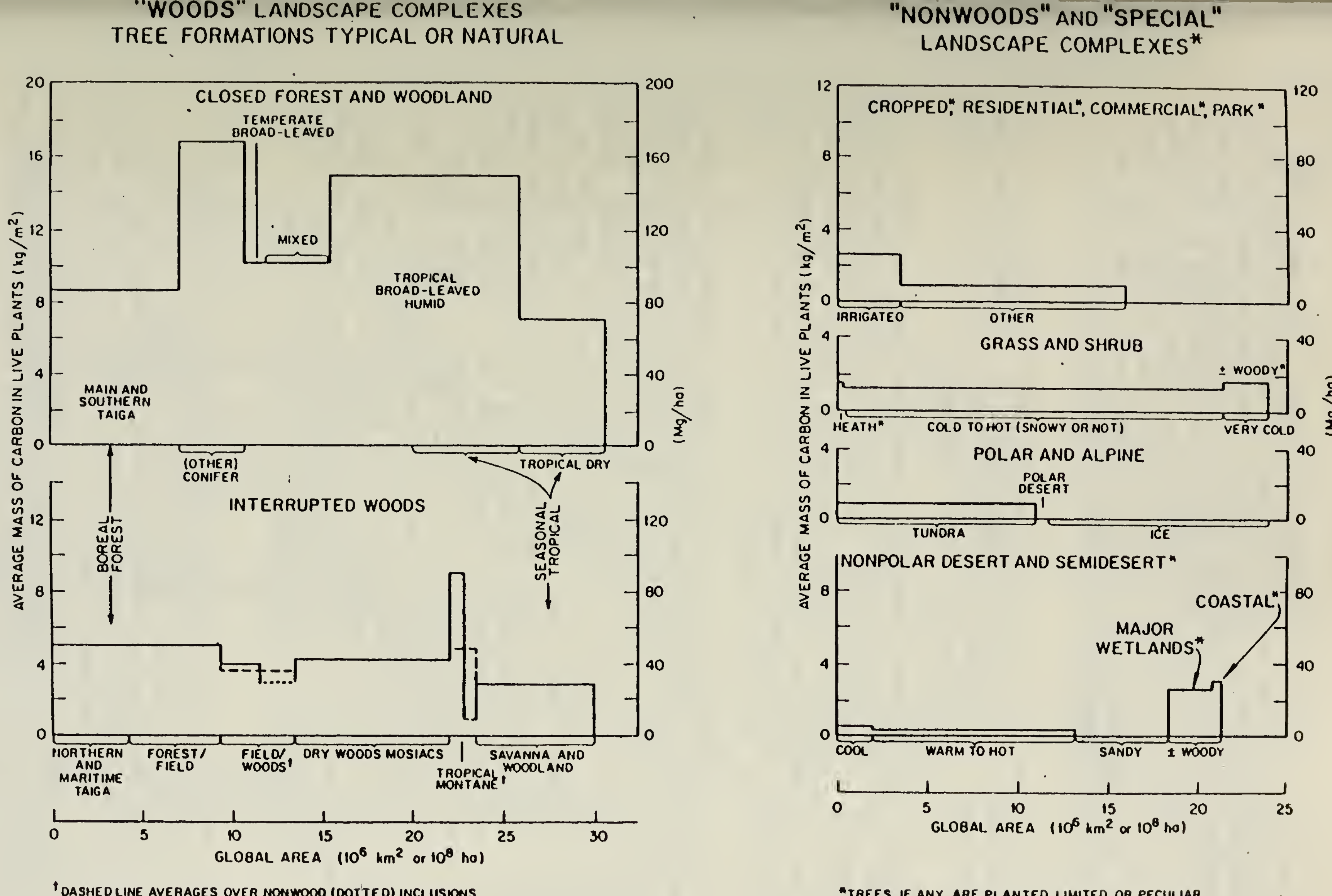


Figure 2. A bar graph summary of the areas (horizontal axis) and approximate carbon per unit area (vertical axis) averaging over the major complexes of vegetation or landscape complexes, from the map of Olson and Watts (1982) and sources of Olson et al. (1978, 1983). The product of land area and carbon per unit area indicates a current medium estimate of total carbon in plant biomass in various kinds of forests and other woods (left) and nonwoods or special (wetland, coastal) landscapes (right). Two impact problems under investigation at Oak Ridge National Laboratory are: (1) How would life zones be relocated with a changing climate, altering the areas left for each? (2) How soon might the losses of plants no longer adapted to the new climate be matched (if at all) by the arrival and growth of better adapted plants? (Jerry S. Olson)

crops only occupy the ground for a fraction of the year. That means that the processes of quick burning during land clearing and hastened decay of the debris that was left and not burned promptly have given an excess of CO_2 into the atmosphere, averaging something like half a billion metric tons of carbon a year. Historical records of change in area (like those in Figure 3) and estimates of changes in the carbon per unit area (after Figure 2 and related data) show a release rate since 1860 averaging near 500 million tons of carbon per year from clearing of land for censused crops. Most CO_2 release was in the north temperate grain belts before 1920, and in various southerly countries thereafter.

Probably even higher rates of release were made by deforestation of lands that regrew to forest or at least to scrubby rangeland. In some places, the regrowth of new forest and recovery of soil has offset some of the very rapid releases that continue in many overpopulated nations.

Many other changes that diminish live carbon have taken place on forest lands. A shift from long-rotation timber to pulpwood harvest cycles helps to lower the average plant mass and carbon. The world total release could well be nearly 0.8 to 1 billion tons a year, expressed as elemental carbon. So nonfossil fluxes do not now come close to equalling the fluxes released by the burning of fossil fuels currently; probably they did exceed it until the great petroleum boom of the present century.

Under most tillage systems the soil part of the carbon inventory continues adding to the increase of CO_2 in the atmosphere long after the time of clearing. The diagram in Figure 4 has triangular coordinates of temperature, precipitation and evapotranspiration (for the Holdridge System of Life Zones) which summarize climate either for latitudinal zones from the equator toward the poles (left side) or, within the tropics, from the low altitudes on up to the higher altitudes (right side). My carbon estimate for this world pool of over 1,500 billion tons of carbon come from a kind of synthesis from over 3,000 analyses which Paul Zinke of the University of California, Berkley and collaborators (1984) have organized and computerized over a decade or two. Contours in Figure 4 show quantitatively how the content of carbon exceeds 20 kg c/m^2 not only in the high rainfall areas and snowfall areas of the northern latitudes, but in the tropical mountains with constantly cool, frequently cloudy climate with condensed fog. This triangle scheme of L.R. Holdridge essentially combines temperature and moisture in a way that shows how the hottest, driest desert soils in the lower left-hand corner have very low carbon. There is a very low input and a fairly rapid decay rate (if and when showers ever do come) to allow microbes to break down the organic matter.

In the hot but wet zones, production of carbon input to the soil is high, yet a lot of that carbon is already released by CO_2 in debris as leaves are falling or as they break down soon at the surface of the soil. In the climates which are wet enough to be pretty productive, even though cool and sometimes waterlogged, decay is very slow. There we find the buildup of very deep, wet, black, sometimes peaty types of soils. Here in the Middle West, not only the dry steppe climate so typical of short grasslands but even in some of the subhumid tall grassland soils which potentially could support trees, we have had other interactions that create the high soil humus content typical of the prairie soils, now named "mollisols."

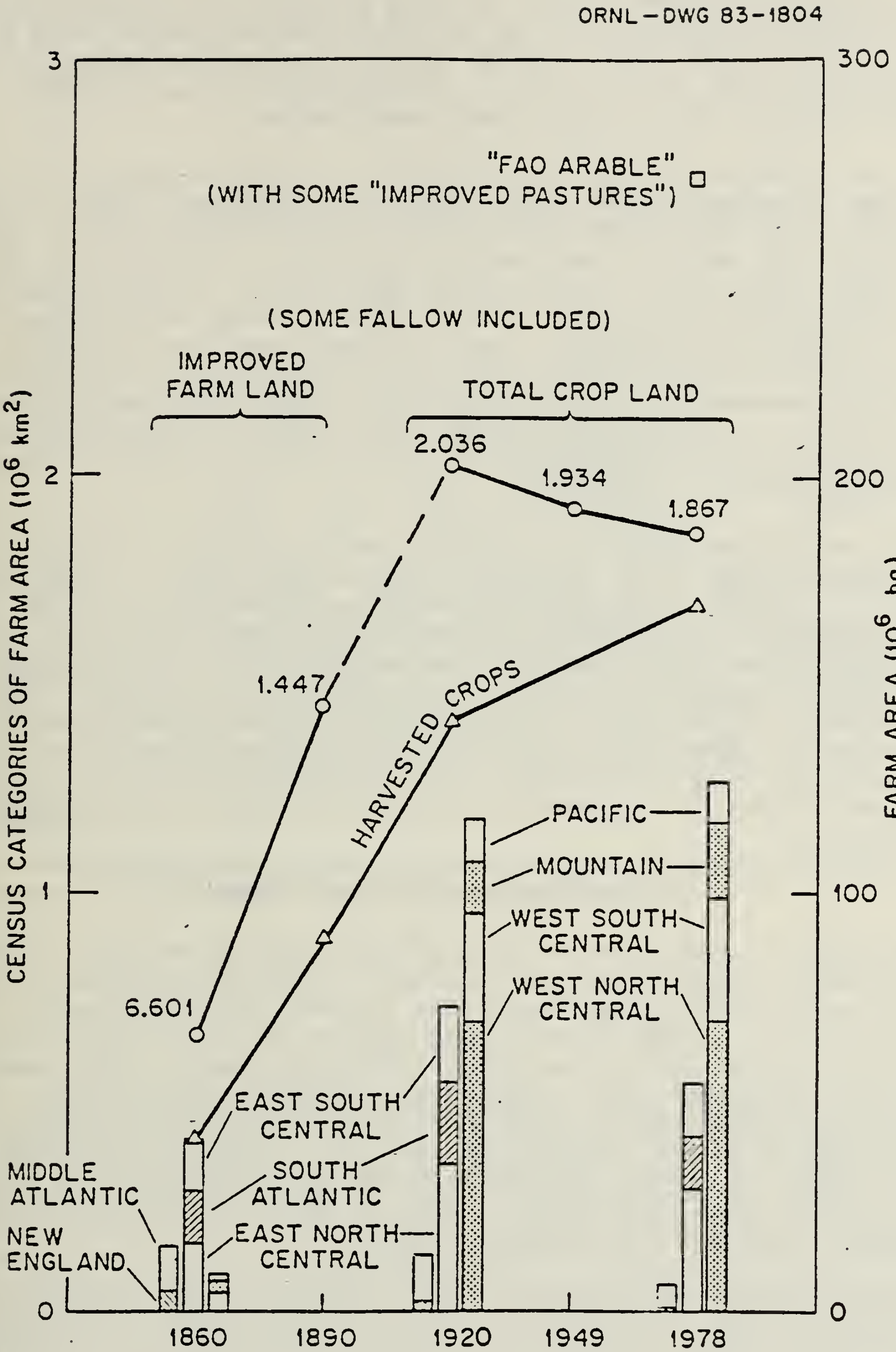


Figure 3. An American example of land clearing for expanded agriculture around the world shows declines of censused crop area in New England and the Middle Atlantic States after 1860, rapid increases elsewhere in the East and Midwest until 1920 (with local reversion thereafter), and less increase in the mostly-dry Pacific and Mountain States (Jerry S. Olson, John F. Richards and Ralph M. Rotty, 1983).

In summary, converting land with high live biomass from woods to crops or other nonwoods vegetation and the stirring of humus by cultivation have together contributed excess CO_2 to the atmosphere long before there was much burning of fossil fuel. We are trying to improve estimates of that rate of release, and of its history. The balancing of the processes of income and loss of CO_2 is still under investigation.

Models for global carbon cycling that differ in quite a few ways give a general sense of agreement that continuing rise of atmospheric CO_2 is likely. The oceans delay the ultimate disposition of excess CO_2. First, a chemical buffering in the surface layer (equation in Figure 1a) (Baes et al 1976, 1977) means lower uptake of CO_2 as some gets taken up as the bicarbonate ion instead of $CO_3^{=}$ ions in the total dissolved carbon (ΣC) system of the ocean. Then there are physical delays in mixing that have to do with that stratification of well-mixed surface waters above cold, deep layers of the ocean. The overturning of water in the polar zones where surface waters are also cold, and the rather slow physical circulation into deeper parts of the sea, apparently helps take up excess CO_2 a little faster than most oceanographers estimated a few years ago.

Society, in its complex way, will reach a determination on the rates of fossil fuel burning versus the decision to conserve fuels for later generations (Clark 1982). Some analysts' scenarios will continue to lead into extremely high burning release rates for CO_2 and other trace gases, extrapolated fuel burning rates many times as high as the release rates of the present time lead to high curves of CO_2 in Figure 5. Or will the finite resources of available fossil energy at last be projected to last over more centuries in the future? A very low scenario might even turn on down the burning of CO_2 and decrease the rate of depletion of fossil fuel after a few more decades of adjustment of energy technologies (low curves of Figure 5).

ASSUMPTIONS ABOUT CLIMATE CHANGE

I'm not going to argue which of the scenarios about future CO_2 will someday be "right." We must move on to climatic (and then ecological) effects of <u>any</u> given scenario <u>if</u> the fossil fuel use does accelerate again, after a pause in the early 1980s, from economic slowdown and deliberate energy conservation. Figure 5 (after Baes et al 1976) still spans a wide range of alternative assumptions about energy trends, between the higher and lower family of curves (scaled to multiples of the 1860 concentration which we formerly took to be 295 $\pm$ 5 parts per million). Bands of uncertainty related to the fraction of carbon remaining airborne and modified by land use may be growing wider, instead of narrower, until we further understand the basic biology and history of the biospheric carbon.

Several groups of climate modelers still estimate average surface temperature rates near 3°C per doubling of CO_2 (right axis of Figure 5). Perhaps a more conservative estimate will eventually allow for moderating this change because of negative feedbacks which are very difficult to model quantitatively. A guess at the presently unknown sensitivity might settle nearer 2 $\pm$ 1 degrees per doubling on a kind of world average of the surface temperature.

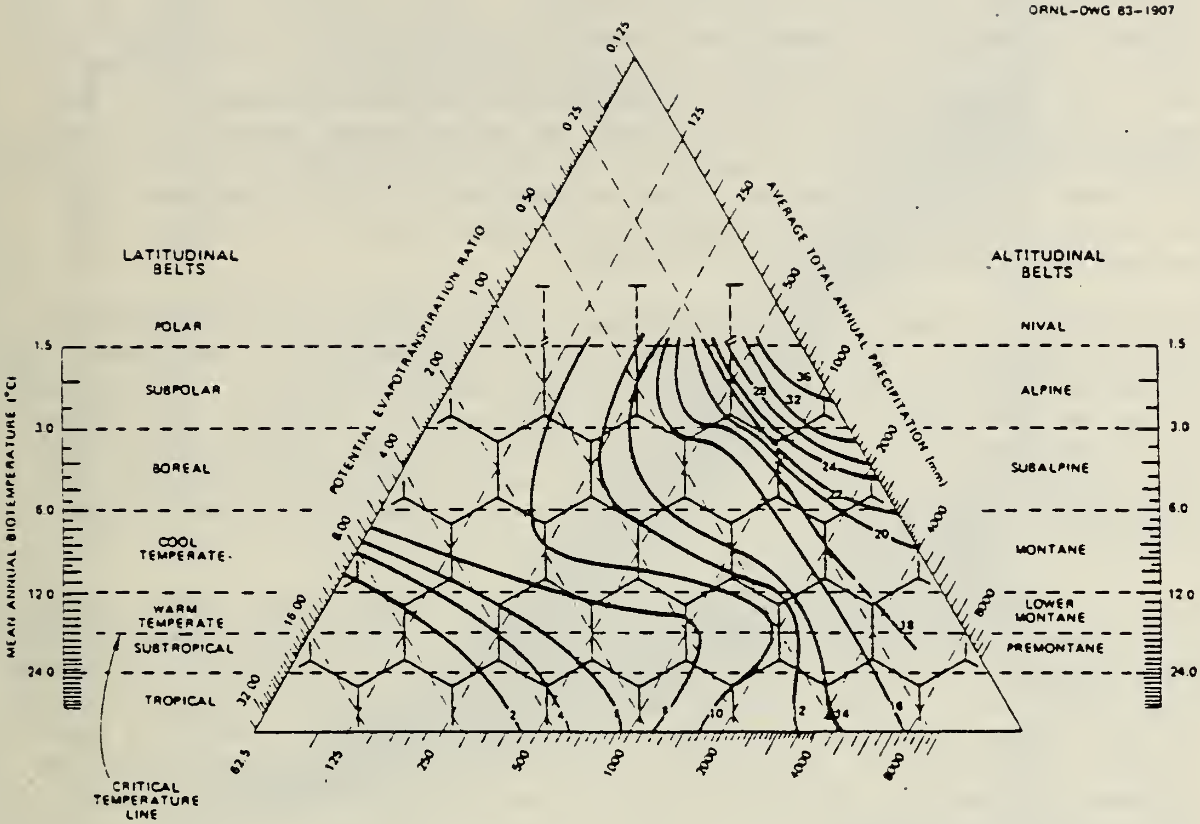


Fig. 4. Soil Organic Carbon (kg/surface cubic meter). Dark curves represent isolines of soil carbon density on the Holdridge Life Zone chart (see Holdridge 1947).

Figure 4. Soil organic carbon (kg/surface meter) in well-developed soils from many climates. Very low humus is typical of hot dry climates (lower left of triangle diagram of L.R. Holdridge life zones) because organic production is low, and decay is rapid. Humus averages are highest in cold wet climates of alpine or subpolar lowland climates, where high moisture favors more organic production than decay under wet, frequently waterlogged or frozen conditions (upper right edge of mapped conditions). Various intermediate conditions and hot, wet climates (lower right for tropical rain forest) tend to have 10 ($\pm$5) kg/C/m^3. From Figure 4.3 of Zinke et al. (1984).

There is also reason to expect more warming than average, perhaps several-fold more, in the high latitudes. There it makes most difference as the snow line melts, so there would be less reflection of energy to space than there was when snow lasted most of the year. Some authors point out uncertainties even in the most ambitious physical modeling. Yet it usually turns out that dissenters from this "conventional wisdom" have made some simplifications of their own for either rhetorical or scientific purposes. So I think the burden is still upon them, rather than upon the most detailed studies of the carbon dioxide and climate, to indicate why we would not expect an average change of these magnitudes, near 2 or 3°C if the CO_2 doubles once; 4 to 6°C if it were allowed to continue a second doubling. If CO_2 alone were not sufficient to make this much change, other gases like fluorocarbons, N_2O and methane might make up the difference.

Many of these climatic model projections suggest that mid-latitudes would have net drying. Diminished precipitation is indicated in a few places. But excess temperature, and the evaporation that would go with it, add leverage to the net hydrologic balance over much wider areas. From our corn states up to southern Canada, and in some parts of the Soviet Union, the vulnerable areas happen to be major grain belts and grassland rangelands of the temperate climate zone. We shall see below that the forest could change drastically as well.

Duvick and Blasing (1983) and Blasing and Duvick (1984) have recently used tree rings from Iowa and Illinois to infer that droughts have long been common. Intervals average near 20 years (22-year Hale solar cycle? 18.6 year lunar-tidal cycle? some combination?) in the cool as well as warm parts of the last three centuries (see Figure 6). How such droughts would be compounded if future mean temperature rises abruptly, or if summer and winter extremes both were to increase, brings us on to the next and main issue: about ecological impacts.

ANTICIPATING KINDS OF IMPACTS FROM HYPOTHETICAL CLIMATIC CHANGE

Contingency planning doesn't have to wait until we have details. (We could go on waiting until history is behind us. Billions of dollars of agricultural loss in the 1983 Midwestern drought could be a price already being paid. However, research has simply not yet reduced the uncertainties from unresolved factors enough to prove the CO_2 connection even if it is already with us.

1. Shifts in Zones of Crop and Resource Use

The next speaker, Silvan Wittwer, will indicate how agricultural production and the business of farm investment can adjust if impacts on cropping can be anticipated. But such planning would involve considerable cost and needs for knowledge. A rather wider range of other impacts could affect the rest of the landscape, about 90 percent of the continent which is not arable land. Many products, future resources and amenities depend on marginal and wild lands. But these do not command enough market value to pay for intensive, expensive protective measures like irrigation. (And, we shall see, the water may not be where we would need it, even if money were waiting to be spent on it.)

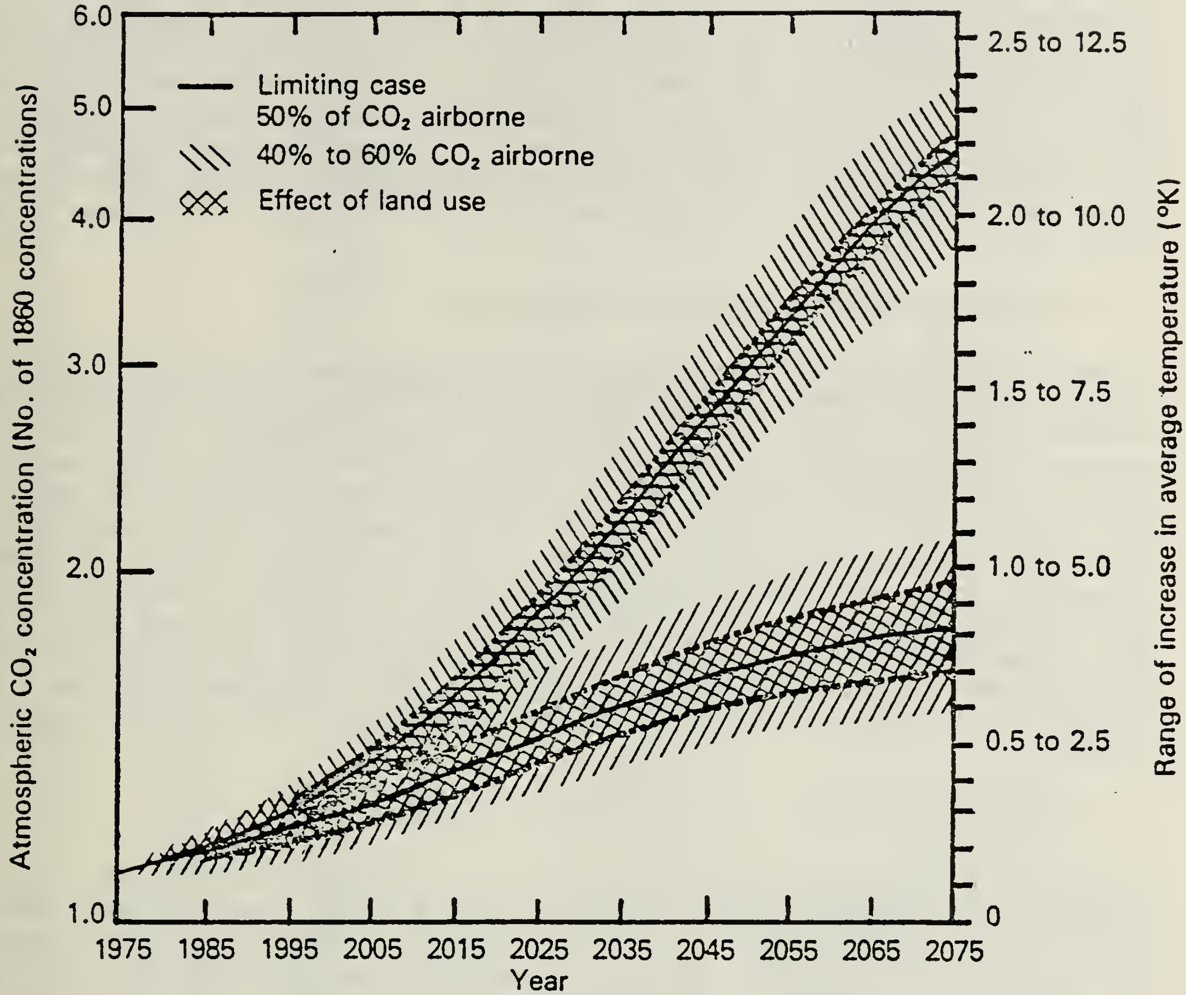


Figure 5. Projected atmospheric CO_2 concentrations and possible changes in the average surface temperature, assuming either low sensitivity to CO_2 (1°C per doubling) or high sensitivity (5°C per doubling). Modifications of this curve (after Baes et al 1976, Olson 1980) due to past and current imbalance of nonfossil carbon in the biosphere have been omitted for simplicity. A range of 1° to 3°C seems a more probable response than higher extremes.

2. Basic Production Balance: Photosynthesis - Respiration

If there is an enhanced photosynthic production stimulated by the excess CO_2, it would not necessarily lead to storage of extra carbon. Stimulated production may be balanced by the return processes of respiration given in my first diagram (see Figure 1a). My next conclusion for farm, forest and other ecosystems alike is: we need better auditing and ecological understanding of both the income and loss sides of our world's budget of organic matter and of all the more important products. How do temperature, moisture and wind interact to affect production rates, turnover rates, and the difference between these?

3. Global Biogeography; Midwestern Examples

Present distributions of the natural global ecosystem complexes as well as farmland would be changed. Generally as some climate belts would be moving northward, so would the zones of vegetation already adapted to each belt of warmth. Also, the prairie peninsula climate, in which most of you reside, may have another opportunity to move eastward as it did 5,000 years ago. Some tree species, like white pine and eastern hemlock, already located naturally in relic locations could be lost, or more stranded in fewer isolated canyons in northern Illinois, Indiana and Ohio. It would be more difficult than before, in patchwork woods isolated by field crops, to have natural reestablishment of seedlings in the new niches of climate and topography unless foresters and conservationists paid the extra cost of establishing the trees artificially. Now that service is done free for most of this continent's forests.

4. Understanding Plants' (and Animals') Programming

Plants adjust their growth and dormancy cycles in ways that may get out of kilter with the altered climate. As in Florida today, some northern trees may no longer get the normal chilling to break the dormancy of their seeds or of their buds. It might be (as for hemlock) that the cycle of light and dark periods could break the dormancy instead - but maybe not effectively enough, promptly enough, to keep those species competitive with their neighbors. Or buds may be formed too early, as they have become adapted to harden off against risk of frost of the autumn season. Other species that are not that conservative in using the available growing time might gain the margin of growth to overtop them. There could be a shift in the competitive effectiveness so that a different mixture of species could become available in the region, depending on which ones are available for migrating.

Drought stresses like we've had in summer of 1983 would lead to a pause in the growth for one year, perhaps followed by survival if conditions return nearer to "normal." But if stresses like this come year after year, many species would die out in wild communities, even if capable of persisting as horticultural specimens on your University campus or the Morton Arboretum.

5. Simulating Long-range Community Shifts

Al Solomon, my colleague at Oak Ridge, and a collaborator with Jim King, has recently completed some computer simulations that keep track of growth and biomass of the forest and the number of trees of many groups (Figure 6a)

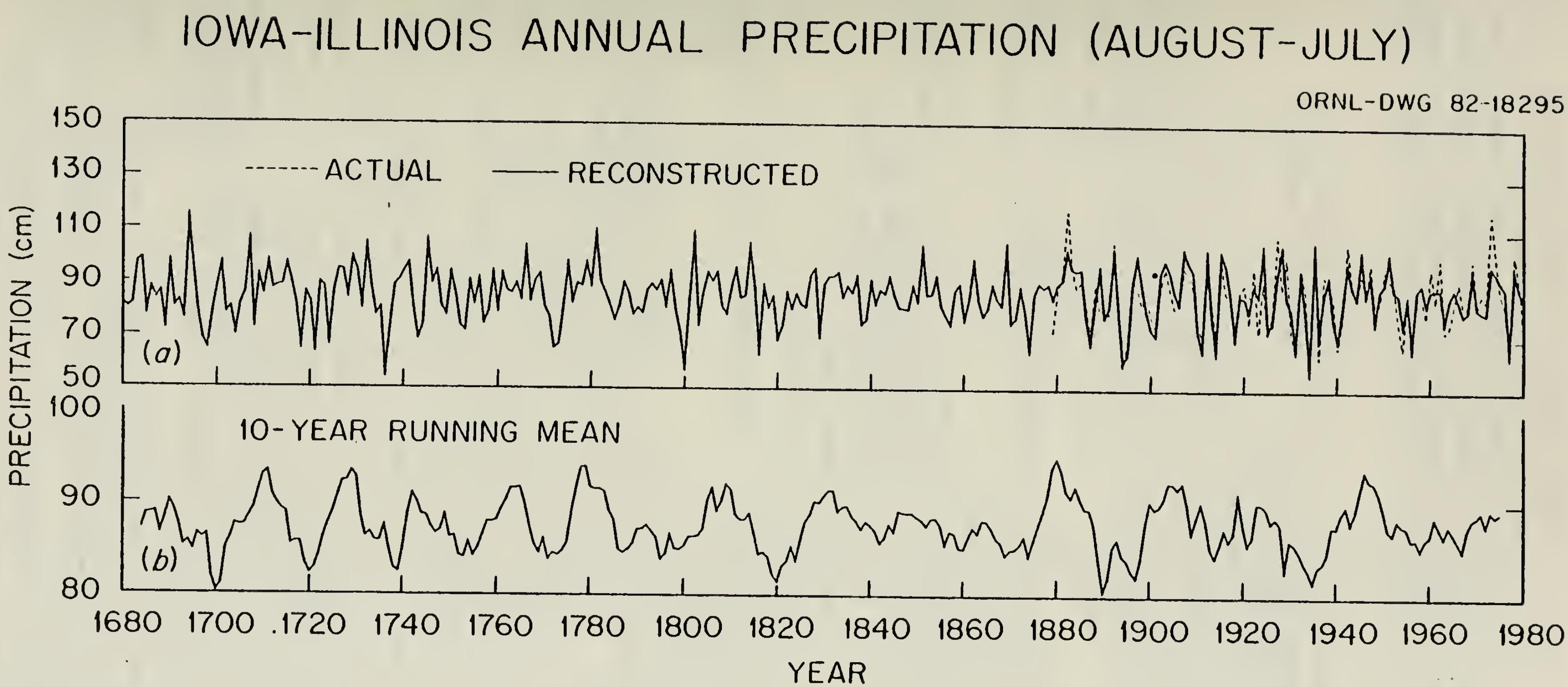


Figure 6. Precipitation inferred from tree rings of Illinois, Iowa and Missouri, by T.J. Blasing and Daniel Duvick (1984: Figure 2 from Nature, vol. 303, pp. 143-145). a, Reconstructed annual (August-July) precipitation for Iowa-Illinois as obtained from the regression equation: $y = -2.788 + 90.756\ x$, where y is the precipitation estimate for a particular year and x is the regional ring-width index for the corresponding year. Actual values including independent data are indicated by the dashed line. When this equation, derived using data from young and old trees, was applied to reconstruct precipitation from only the cores dating back to 1680, the RE statistic corresponding to +0.66 in the text changed negligibly to +0.68. b, The 10-yr. running means of the reconstructions plotted for the fifth year of each 10-yr. sequence. (Blasing and Duvick, 1984)

Figure 7. Computes simulations of forest biomass (above ground) at six sites in Eastern North American forests. After 400 years of simulating "random" and successful fluctuations under present climatic conditions, climate changes the conditions projected by Manabe and Stouffer gradually to 4 times the present level of CO_2 and then remains constant (on average) to suggest fluctuations under the new regime of random weather. Species have the following abbreviations:

ABI:	Abies balsamea (balsam fir), A. fraseri (Fraser fir)
ACE:	Acer saccharum (sugar maple), A. rubra (red maple), A. saccharinum (silver maple)
AES:	Aesculus octandra (yellow buckeye)
BET:	Betula lenta (sweet birch), B. papyrifera (paper birch), B. alleghaniensis (yellow birch), B. populifolia (gray birch)
CAR:	Carya cordiformis (bitternut hickory), C. tomentosa (mockernut hickory), C. glabra (pignut hickory), C. ovata (shagbark hickory), C. laciniosa (shellbark hickory), C. texana (black hickory)
CAS:	Castanea dentata (American chestnut)
CEL:	Celtis laevigata (sugarberry)
COR:	Cornus florida (dogwood)
FAG:	Fagus grandifolia (American beech)
FRA:	Fraxinus pennsylvanica (green ash), F. americana (white ash), F. nigra (black ash), F. quadrangulata (blue ash)
JUG:	Juglans cinerea (butternut), J. nigra (black walnut)
LIQ:	Liquidambar styraciflua (sweet gum)
LIR:	Liriodendron tulipifera (yellow poplar)
NYS:	Nyssa sylvatica (blackgum)
OST:	Ostrya virginiana (eastern hophornbeam), Carpinus caroliniana (American hornbeam)
PIC g:	Picea glauca (white spruce)
PIC m/r:	Picea mariana (black spruce), P. rubens (red spruce)
PIN b/r:	Pinus banksiana (jack pine), P. resinosa (red pine), P. rigida (pitch pine), P. echinata (shortleaf pine), P. taeda (loblolly pine), P. virginiana (Virginia pine)
PINs:	Pinus strobus (white pine)
PIA:	Platanus occidentalis (sycamore)
POP:	Populus balsamifera (balsam poplar), P. grandidentata (bigleaf aspen), P. tremuloides (trembling aspen)
PRU:	Prunus serotina (black cherry)
QUEN:	(Northern) Quercus alba (white oak), Q. coccinea (scarlet oak), Q. prinus (chestnut oak), Q. rubra (northern red oak), Q. velutina (black oak), Q. macrocarpa (bur oak), Q. borealis (gray oak), Q. ellipsoidalis (northern pine or Hill's oak)
QUES:	(Southern) Quercus falcata (southern red oak), Q. lyrata (overcup oak), Q. marilandica (blackjack oak), Q. muehlenbergii (chinkapin oak), Q. nuttallii (Nuttall's oak), Q. palustris (pin oak), Q. shumardii (Shumard's oak), Q. stellata (post oak), Q. virginiana (live oak)
THU:	Thuja occidentalis (northern white cedar), Juniperus virginiana (red cedar), Larix laricina (tamarack)
TIL:	Tilia americana (American basswood), T. heterophylla (white basswood)
TSU:	Tsuga canadensis (hemlock)
ULM:	Ulmus americana (American elm), U. alata (winged elm)

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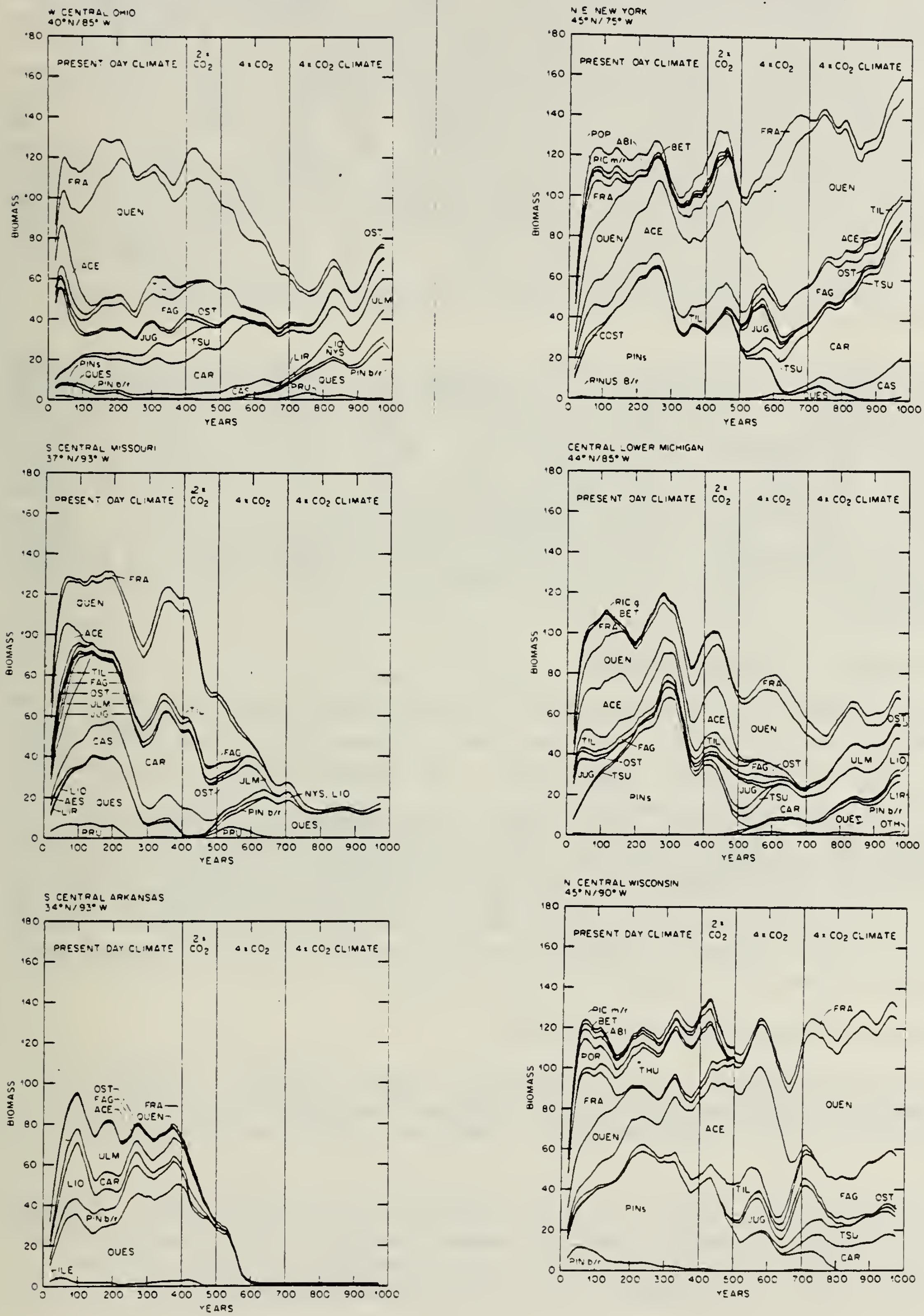
W. DECIDUOUS FOREST

N. DECIDUOUS FOREST



after an assumed doubling of the CO_2 400 to 500 years from the starting time, and a quadrupling in the following 200 years. While there was no Illinois station in this computer exercise, the "Western Deciduous Forest" graphs (left of Figure 7) suggested more loss in average mass of the species now growing there than replacement by oak (and gum) trees of more southerly distribution (Ohio is the upper left case of Figure 7). Only a sparse cover (like a savanna) of the latter species was indicated for south central Missouri (left center panel) where there are also northern oaks, hickories and many other lesser species in closed stands under the present climate. For south central Arkansas projections (lower left), all trees fail to grow enough to keep alive in the present coding of the computer program, and it is not yet "loaded" with subtropical or savanna species that might conceivably be more suited to growing with grass or shrubs in the hypothetical climate of 4 x CO_2. "Northern Deciduous Forest" (right) also shows important changes in relative composition of species, with high mass and carbon retained in northern New York and Northern Wisconsin, and diminished values for central lower Michigan.

Of other cases of Al Solomon's (1984) simulation, not shown, one south end of Hudson Bay showed a replacement of tundra-like vegetation by a boreal forest moving northward. A shift from spruce fir to something more like a transitional northern hardwood conifer forest occurred just north of Lake Superior, around Lake Nipigon. In our Tennessee climate oaks, hickories and some species with more mesophytic (moisture-requiring) character shift to live oak and gums, pignut, a kind of vegetation now down in the coastal plain. On the other hand, even these simulations don't fully take into account the effects of drought or the higher fire probabilities that would be coming along with that drought.

6. Ocean Level and Beach Changes

These local effects are examples of generic ones that would affect the biosphere around the world. The ocean shores also will continue creeping up even if there is not such a sudden ocean rise as some people have suggested.

There is an attitude saying, "Well, since those changes are conjectural, we'll wait and not alarm people too much about them." A great deal of property loss of life already occurs due to storm disasters that come on very suddenly. Yet even the ocean's slow upward creep, will be translated into a wide horizontal shift in the edges of the salt marshes and adjacent property. Loss of life and property around the ocean shores will just be enhanced when later storm surges rise higher than ever before.

7. Great Lake Shores and Water Balances

I was really interested in the proceedings of your last year's meeting on water supplies. The water balance of rain and evaporation would affect runoff and the water levels of rivers (Wendland and Watson-Stegner, 1983) and lakes.

You people are closer than I am now to problems in the Great Lakes, including costs of maintaining harbor uses and adequate sanitary flows down the Illinois River. Some of you individually are responsible for policy-related implications that the newspapers are receiving about Canadians, the U.S. and

the interests of various states. My own work (Olson 1958) concentrated on how the Lake Michigan water levels affected both the widening of beaches and dunes, and their subsequent erosion. The general downward trend of the Great Lakes since the last century reached the lowest level of all time in 1964. There has been a lot of shore property loss in the cycles of higher water level since then. Superimposed on the broad trend were alternatives with periods of 11 years. Data of this kind suggest needs for further study of how the Great Lakes' own water balance relates to the regional hydrologic changes. Thus, your 1982 and 1983 meeting themes suggest an agenda for yet another meeting, perhaps a workshop at which the people representing different business or public responsibilities could converse about which kinds of foresight or planning could ameliorate the impacts of hydrologic and climatic change.

8. Wind Actions Affecting Landforms (e.g., Sand Dunes)

Some of my work on sand dunes around Lake Michigan indicates that their forms and directions and intensity of movement all changed with the 18 varied climates of postglacial time. The "dust bowl" of the 1930s and 1950s in the Great Plains was directly related to short-term oscillations like we noted from tree rings and water levels. The winds themselves reflect shifts in air masses that reflect global change and have some impacts on regional landscapes. As the prairie grasslands are being "plowed out" again for risky short-term gains by speculators or subsidy collectors, the resources of landforms and soils that took many thousands of years to create may once more be in jeopardy whenever the next dry, hot windy crisis comes. We may be better prepared technically to learn from earlier dust bowls and more ready socially to help the victims of "grapes of wrath." "How might individuals and organizations in each part of our country respond to the combined changes of winds, temperatures and precipitation changes?" is a question for the agenda of future years.

Again, I congratulate the organizers of this meeting for getting such varied interests together. You can see how additional connections (like those of climate to the insects we heard about yesterday) would further complicate the shifts in the overall ecological balance. The whole world and your neighbor's farm each face uncertainties. Yet each can examine and perhaps alter the odds for meeting troubles or opportunities.

Thank you.

References

Baes, C.F., Jr., H.E. Goeller, J.S. Olson, and R.M. Rotty. 1976. The global carbon dioxide problem. ORNL-5194. Oak Ridge National Laboratory, Oak Ridge, TN.

__________. 1977. Carbon dioxide and climate: The uncontrolled experiment. Am. Sci. 65:310-320.

Blasing, T.J. and D.N. Duvick. 1984. Reconstruction of precipitation history in North American corn belt using tree rings. Nature 307:143-145.

Clark, W. (ed.). 1982. Carbon Dioxide Review: 1982. Oxford University Press, New York. 469 pp. plus Plate 1.

Duvick, D.N. and T.J. Blasing. 1983. Iowa's oldest oaks. Proc. Iowa Acad. Sci. 90(1):32-34.

Olson, J.S. 1958. Lake Michigan dune development. 3. Lake-level, beach, and dune oscillations. J. Geology 66(5).

Olson, J.S. 1964. Gross and net production of terrestrial vegetation. J. Ecol. 52:99-118.

Olson, J.S. 1970a. Carbon cycles in temperate forests. pp. 226-241; 1970b. Geographic index of world ecosystems. pp. 297-304; 1970c. Continental ecosystem patterns and reconstructed living carbon prior to the Iron Age. Back flyleaf. IN D.E. Reichle (ed.), Analysis of Temperate Forest Ecosystems. Ecological Studies No. 1. Springer Verlag, New York. Man's Impact on the Global Environment. MIT Press, Cambridge, Massachusetts.

Olson, J.S., H.A. Pfuderer, and Y.-H. Chan. 1978. Changes in the global carbon cycle and the biosphere. ORNL/EIS-109. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Olson, J.S. 1981a. The role of the biosphere in the carbon cycle. pp. a125-a140. IN R.A. Fazzolare and C.B. Smith (eds.), Beyond the Energy Crisis, Vol. 4. Pergamon Press, New York.

Olson, J.S. 1981b. Carbon balance in relation to fire regimes. pp. 327-378. IN H.A. Mooney, T.M. Bonnicksen, N.L. Christensen, J.E. Lotan, and W.A. Reiners (eds.), Fire Regimes and Ecosystem Properties. USDA For. Serv. Gen. Tech. Rep. WO-26.

Olson, J.S. 1982. Earth's vegetation and atmospheric carbon dioxide. pp. 388-398. IN W.C. Clark (ed.), Carbon Dioxide Review: 1982. Oxford University Press, New York.

Olson, J.S., and J.A. Watts. 1982. Major World Ecosystem Complexes, Ranked by Carbon in Live Vegetation. Oak Ridge National Laboratory, Oak Ridge, TN.

__________, J.A. Watts, and L.J. Allison. 1983. Carbon in live vegetation of major world ecosystems. ORNL-5862. Oak Ridge National Laboratory, National Technical Information Service, Springfield, VA.

SCEP (Study of Critical Environmental Problems)

Solomon, A.M., M.L. Tharp, Darrell C. West, G.E. Taylor, J. Warren Webb, and J.L. Trimble. 1984. The response of unmanaged forests to CO_2-induced climate change: available information, initial tests, and data requirements. DOE/NBB-0053, United States Department of Energy, National Technical Information Service, Springfield VA 22161.

Wendland, W.M. and D. Watson-Stegner. 1983. A technique to reconstruct river discharge history from tree rings. Water Resources Bulletin 19(2).

AGRICULTRUAL IMPACTS OF CHANGES IN CO_2

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INTRODUCTION

Three important points are emphasized in this paper. First, agriculture can cope with environmental or climatic changes as predicted by the general circulation models of the climatologists. Significant interannual climate variations already exist in all the major food-producing areas of the earth equal to those predicted from a doubling of the atmospheric CO_2. Second, because of the climatic and environmental constraints which now exist for agricultural production--both for stability and magnitude, highest priority should be given to research on alleviation of climatic or environmental stresses for crops and livestock. Third, the biological or direct effects of elevated levels of atmospheric CO_2 are real and intimately linked with climatic effects or impacts. Attention should be given to a research agenda which will delineate these effects on photosynthesis, crop productivity, harvest index, and greater resilience to climatic stresses (water, temperature, light), air pollutants, and problem soils. These research priorities were among the objectives of the International Conference on Carbon Dioxide and Plants held at the United States Department of Agriculture's Russell Center in Athens, Georgia, May 23-28, 1983.

According to those that have observed our home in space, the planet earth is a wonder to behold. Of all the heavenly bodies observed in any detail, it is the only one that has the endowments of land, water, light, atmosphere, energy and temperature to adequately support human habitation as we know it. We live on a unique planet, a floating blue jewel in space that has a curious concurrence of properties necessary for life.

Currently there are changes taking place in the earth's atmosphere which could impact life-supporting systems. Human society is inadvertently conducting a great biological and environmental experiment, the outcome of which is not known. Atmospheric carbon dioxide is now increasing at the rate of 1 1/2 to 2 parts per million per year. It has risen from 315 to 344 parts per million in the last 25 years, a 9 percent increase. Aside from projected effects on climate, CO_2 is also among the factors which because of its currently low atmospheric concentration is suboptimal for plant growth. Hence, the current and projected global increases may be beneficial. The effects on plant growth from "fertilization" of extra carbon dioxide has not been measured but a 5 to 10 percent increase in crop productivity may already have occurred.

CLIMATE EFFECTS

We shall first discuss the possible climatic effects of a rising level of atmospheric CO_2 as far as agricultural productivity is concerned. A record of the composite index of crop yields for the United States shows a very rapid rise during the decades of the 1950s and 1960s. There were marked deviations from the normal, however, during the drought in the mid-1930s. In 1970 there was the southern corn leaf blight, a drought in 1974, and major droughts and heat waves in 1980 and in 1983. For this current year, 1983, it is projected that there will be over a 50 percent reduction in the production of corn and grain sorghum and 33 percent less soybeans than a year ago induced partly by a heat wave and a drought and in part by the Payment in Kind (PIK) government program that reduced the cultivated acreage by almost 25 percent, or 83 million acres, in the United States. This year, 1983, may prove to be the year of the most dramatic cut-backs in grain production for the United States witnessed in the 20th century.

World grain production in the major producing areas of the world has shown a consistent rise from 1960 to 1982. These areas include the United States, the People's Republic of China, the Soviet Union and Southeast Asia. Great variations, however, have occurred in grain production in the Soviet Union, conditioned by millions of hectares of cultivated land which are marginally cold and dry. The Soviet Union cannot consistently feed itself.

If one were to plot the yields of major crops in many nations on earth, one would see during the past two decades significant increases in overall productivity. These increases, however, also show marked deviations from the normal, caused by climatic impacts, namely, drought, floods and heat waves. This is true of the average wheat yields in Washington and Oregon, grain production in the Punjab of India and for rice production in China, Indonesia and in Taiwan.

World grain production has increased almost threefold from 1950 to 1982. While there has been little change in the millions of hectares devoted to grain production, yields have more than doubled, and the amount of grain produced per person on the earth today is greater than for any other time in history.

A consideration of possible climatic changes induced by rising levels of atmospheric CO_2 should focus primarily on the 21 crops which stand between people and starvation. These include the cereal grains--rice, wheat, corn, grain sorghum, millet, oats and barley. As a group, they provide 60 percent of the calories and 50 percent of the protein that people consume on the earth. The second large food group are the legumes which provide approximately 20 percent of the protein consumed by people. The most important legume crop, globally speaking, is the soybean. Also included are field beans, chickpeas, pigeon peas, mung beans, cowpeas and peanuts. A third large food group includes the tuber and root crops, the most important of which is the potato, which is considered by many as the fourth most important world food crop. Included also are the sweet potato, adapted to hot, humid conditions, and the cassava, commonly known in the United States only in the granulated form. It is called tapioca. The sugar crops, sugar cane and

sugar beets, are an important food group and contribute 15 to 17 percent of the total calories consumed by people on earth. We conclude our list of 21 crops by adding the banana and the coconut, the tropical crops, which make a great contribution not only to people in the tropics but also those in temperature zones. One could also add to these 21 crops, which now stand literally between people and starvation, some new crops such as the winged bean, triticale, the oil palm and the sunflower. These crops, along with others, can assume importance in the future and their response to elevated levels of atmospheric CO_2, both as to climatic change as well as to possible biological influences, should be addressed.

CLIMATE-BIOLOGICAL INTERACTIONS

Agriculture is the only major industry that processes solar energy, and the crops that we produce are so planted in designs and patterns that they may capture as much energy from the sun as possible. Green plants are essentially biological sun traps. This is particularly true of the corn plant which in much of temperature-zone agriculture will produce more total digestible nutrients than any other crop. In agriculture we are concerned about biological productivity and the balance of energy, water, soil nutrients and carbon dioxide in the atmosphere.

The major resource inputs into food production include climatic, land, water, energy, fertilizers, pesticides, mechanization and human capital. There are also some unique endowments of American agriculture which include the land grant university system, the inputs of the private or industrial sector, the free enterprise system, the English language, and finally the climate resource which provides dependable production at high levels.

It is the climate resource which is our concern with respect to the rising levels of atmospheric CO_2. The climatic variables that may be affected by elevated levels of atmospheric CO_2 include temperature, sunlight, precipitation patterns and length of the growing season. But coupled with possible climatic impacts are influences on biological processes that are also affected by rising levels of atmospheric CO_2. These include photosynthesis, yield and biomass, harvest index, biological nitrogen fixation and resilience to environmental stresses.

One cannot entirely separate the possible biological and climatic effects of a rising level of atmospheric CO_2. They overlap in response to light, production of biochemical metabolities, pest resistance, temperature tolerance and water use efficiency. The projected climate effects of a rising level of atmospheric CO_2 expressed as higher temperatures are latitude-dependent. The effects will be greater at the poles than at the equator. Secondly, modification of the precipitation patterns are projected along with an increase in water requirements by plants because of higher temperatures. Thirdly, there should be increases in length of the growing season in temperature-zone agriculture.

ADAPTABILITY OF AGRICULTURE TO CHANGE

Agriculture can be expected to cope with climate change. Individual crops show great adaptability to wide differences in climate. Rice can be grown

from the equator to as far north as the 45th latitude. It is produced in every province and autonomous region in China and very successfully. Wheat and barley can be grown almost as far north as the Arctic Circle and in most all parts of the world where commercial agriculture exists, except under hot, humid conditions. Corn, as a major food crop, can be grown from the equator to the 45th latitude or even further north. It likewise is found in every province in China, on the island of Java in Indonesia, and the Punjab of India. Potatoes are grown extensively in almost every nation on earth and the range in productivity can extend from Alaska to the equator. Sorghum, while adapted to hot, dry conditions, can be grown extensively from the equator to the 45th latitude. Similarily sunflowers can be grown in every state in the United States, all countries in Latin America, and in every province in China and as far north as the Arctic Circle and extending to the equator. Soybeans, likewise, show excellent production on the island of Java near the equator, the Punjab of India, the Heilongjiang Province of the People's Republic of China, and from the Gulf of Mexico to Minnesota in the United States. Dr. Wang Jingling of the Northeast Agricultural College, in China, has extended the climatic adaption to as far north as the 53rd latitude and at 300 meters elevation in Manchuria.

There are many other examples of the adaptability of agriculture and its ability to cope with change. Hybrid corn, after its commercial introduction, achieved a 95 percent adaption in Iowa in a period of seven years. Corn in western Europe increased from almost no acreage in the early 1960s to hundreds of thousands of acres at the present time. Rice production in Indonesia has been doubled in the past decade and wheat production in Turkey has doubled. There has been a threefold increase in grain production in the Punjab State of India since the mid-1960s.

Other examples of rapid change in agricultural practices include: cash cropping in the Corn Belt as an alternative to mixed crop-livestock systems; irrigation on the high plains; the rise of conservation tillage for the production of corn and soybeans; and the use of Atrazine for weed control in corn, which now has achieved a level of 75 percent of the corn acreage of the United States.

Climate is the most determinate factor in agricultural productivity. The climatic hazard that farmers fear most is drought. Other problems include floods, heat waves, hail, early and late frosts, delayed cold wet springs and interactions with disease outbreaks. A classical example of climatic interaction with disease outbreak was the spread of the southern corn leaf blight in 1970 prompted by a wave of hot moist air in the Mississippi Delta that moved north into the Corn Belt. The single most important climatic factor determining agricultural productivity in the corn and grain belts of the United States is the amount of snowfall in winter and subsequent soil moisture in the spring. Precipitation in late July and early August can also be important as witnessed in 1983.

Drought, however, can be overcome in part, by irrigation. This has occurred during the past two decades in India where hundreds of thousands of tube wells have been installed. Failure of the monsoons will not have the impact

that it had 25 years ago. Also important in drought resistance is the planting schedule; it is not only the amount of rainfall, it's the distribution. Changing the planting date for a crop such as corn or soybeans may have a major impact on its productivity in a particular season. If drought and heat waves could be predicted well in advance of the growing season one could alleviate, in part, the effects of drought by lowering the plant population, by conservation tillage and by scheduling plantings to optimize the available moisture.

The year 1983 has posed a special agricultural production problem for the United States. With the government's Payment in Kind (PIK) program, cropland was reduced by 83 million acres, or by almost one-fourth of the total. This was followed by a major drought and heat wave, which reduced production of soybeans, corn, grain sorghum, cotton and other important crops to more than one-half to two-thirds the level of 1982.

Important for the future in view of the rising level of atmospheric carbon dioxide and its possible impact on climate change is research for greater resilience to environmental stresses. Areas of investigation should include genetic adaptation and eventually utilizing the tools of genetic engineering, changes in cultural practices, including protected cultivation and chemical treatments for modification of crop response to temperature constraints and for greater water use efficiency.

There is now considerable experimental evidence that with the rising level of atmospheric carbon dioxide, water use efficiency will be increased. There will also be an alleviation of stresses not only from a lack of moisture but from light deficiencies, possible deficiencies in mineral nutrient supplies and from both abnormally high and low temperatures. Interactions of climatic with biological impacts of rising levels of atmospheric CO_2 will likely be numerous in the decades ahead.

BIOLOGICAL EFFECTS

Biological effects of elevated levels of atmospheric CO_2 have been demonstrated since the beginning of the 20th century through extensive greenhouse experiments in western Europe and in the United States. A doubling or tripling of the atmospheric level of carbon dioxide within an enclosed greenhouse structure has resulted in significantly higher yields, earlier maturity and improvements in quality of many vegetables and flower crops. This is particularly true of lettuce, tomatoes and cucumbers grown in mid-winter.

Higher than normal levels of atmospheric carbon dioxide compensate, in part, for light deficiencies and greatly enhance the growth and maturity of the crops. Recent results with soybeans are also comparable. The greatest increases in weight of seed pod and in the growth of roots, leaves and stems occurred between 340 and 520 parts per million. What is needed in modern day research on the biological effects of rising levels of atmospheric carbon dioxide as to biological responses are carbon dioxide which range from 25, 50, 75 or 100 parts per million above the ambient level of the atmosphere which is now about 345 parts per million.

One objective of an international conference held May 23-28, 1982 in Athens, Georgia was to establish a research agenda relating to the biological responses of plants to rising levels of atmospheric carbon dioxide. Attention was directed toward the effects on carbon metabolism, physiological impacts, plant growth and development, microbial influences, and to terrestrial and aquatic plant communities.

Experiments thus far conducted indicate that elevated levels of atmospheric carbon dioxide tend to alleviate deficiencies of sunlight, the toxicities of air pollutants, and some nutrient deficiencies and excesses. Greater water use efficiency is apparently universal for all species.

There is a marked difference as to the effects of elevated levels of carbon dioxide on crops as to whether or not they have C_3 or C_4 metabolism. Most agricultural and major food crops and forest trees have C_3 metabolism and show positive growth responses to elevated levels of atmospheric carbon dioxide. They include rice, wheat, sugar beets, sweet potato, Irish potatoes, cassava, cotton, soybeans, and most fruits and vegetables. Food crops with C_4 metabolism include corn, grain, sorghum, sugar cane and millet. They are less responsive to elevated levels of carbon dioxide but respond by increased growth because of the positive effects of elevated levels of carbon dioxide for greater water use efficiency.

Crop/weed and other crop/pest relationships will also be important for the future as atmospheric levels of carbon dioxide continue to rise. Weeds are among the most damaging of all crop pests. Since most crops have a C_3 carbon metabolism and most weeds are C_4 carbon meatbolism plants, one would expect with rising levels of atmospheric carbon dioxide that the C_3 food crops could compete more effectively with weeds. This is because most weeds are C_4 plants and C_3 plants have been demonstrated to respond much more dramatically to elevated levels of carbon dioxide than C_4 plants. Seventeen of the 21 plants that feed the world are C_3 plants, and of the 18 worst weeds 14 have a C_4 photosynthetic pathway.

Some estimates have been made, with respect to increases in productivity, that may be expected, from a doubling of atmospheric carbon dioxide. It has been suggested that there could be a 40 percent increase for C_3 plants. Also a 5 to 10 percent increase in productivity may already have occurred as a result of increased levels of atmospheric carbon dioxide which now exist. It has also been projectd that both C_3 and C_4 plants would benefit but with a greater response from the C_3 plants.

Within the list for future agricultural and food research priorities is greater resilience to environmental stresses. If there is to be a pronounced climate change as predicted by climate modelers as a result of elevated levels of atmospheric CO_2, a major research investment should be initiated now for achieving greater resilience of plants to environmental stresses as well as to the effects on photosynthesis, biological productivity, biomass production and harvest index.

If one were to project increases in crop productivity for the next 50 years, one would note that some of the increases would occur from a rising level of

atmospheric carbon dioxide. It has been projected that a doubling of current carbon dioxide levels in the atmosphere might result in productivity increases in the range of 20 percent compared to 35 percent for plant breeding, 33 percent for irrigation of crops to conserve water, and 25 percent each from genetic engineering and the use of plant growth regulators. One should be mindful, in reviewing average crop yields of today and those factors which are limiting their productivity that the current suboptimal level of carbon dioxide in the atmosphere is a constraint for optimal performance. It can be expected that with increasing levels of atmospheric carbon dioxide crop productivity will increase. This increase would characterize all of the major food crops.

WATER RESOURCES

Most important of all, however, relative to the carbon dioxide issue is the issue of water resources for future agricultural productivity. Water will likely become the most crucial of all resources for food production. Currently there is an annual overdraft of 20 to 25 million acre feet of groundwater in the United States. Major efforts are underway in many nations to improve and optimize water resource availability for agricultural crop production. Nations that recognize the importance of water as the limiting factor in agricultural productivity include India, China, the USSR, Sri Lanka, Taiwan, Mexico, countries in the Middle East, those in the semi-arid tropics and Egypt. Some of the most extensive water conservation projects in the world are in the People's Republic of China where about 50 percent of the cultivated land is irrigated. Crop irrigation extends from the very southern provinces to the automonous regions of the far northwest. For the past 20 years, China has experienced the greatest stability in crop production of any major grain-producing nation. This stability has been achieved, in part, as a result of the vast cropland areas which are irrigated.

Improved water resources is the one option both for greater dependability and for enhancement of total agricultural productivity for the future. This is true for China, India, the Soviet Union, the United States, Indonesia, the entire Arab world and all countries in the semi-arid tropics. We will witness progressively worldwide increases in areas of croplands that are irrigated. The reason will be both for dependability and for enhancing the total magnitude of production.

One of the great challenges for the future will be to utilize salt or saline water for crop production and to genetically alter plants that they might respond to water derived from estuaries and the oceans. Some progress is currently being made in this direction.

CONCLUSIONS

Whether or not there is to be climate change as a result of the rising levels of atmospheric CO_2, a major research effort should first be mounted to achieve greater resilience to environmental stresses in crop productivity. This will help amend any significant CO_2-induced climate change and will provide means for more effectively coping with already extant interannual

variations in climate. Secondly, one should address the importance of improved water resources. Irrigation currently consumes 80 to 85 percent of the total fresh water in the United States and there is a current overdraft of 20 to 25 million acre feet per year of groundwater, most of which is used for crop irrigation. Current water use efficiency in the United States is at the low level of only 35 to 40 percent. The demands of water for purposes other than agricultural production will increase in the future. These will include those attendant to rising populations and increasing affluency of people for recreation, for industrial purposes and for energy extraction. Supplemental irrigation in sub-humid areas in the United States will become increasingly important to achieve both dependability and enhancement of total agricultural productivity.

REFERENCES

Idso, S.B., 1982. Carbon Dioxide: Friend or Foe? IBR Press, Tempe, Arizona.

Lemon, E.R., ed. 1983. CO_2 and Plants: The Response of Plants to Rising Levels of Atmospheric Carbon Dioxide. Westview Press, Inc., Boulder, Colorado.

Wittwer, S.H., 1980. Carbon dioxide and climate change: an agricultural perspective. Journal of Soil and Water Conservation, 35(3): 116-120.

Wittwer, S.H., 1983. Rising atmospheric carbon dioxide and crop productivity. HortScience, 18(5): (In Press).

MONITORING AND CHEMICAL CHARACTERISTICS OF PRECIPITATION QUALITY IN THE UNITED STATES

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INTRODUCTION

The chemistry of precipitation has been a scientific curiosity dating back many, many years. The first serious work, available in some libraries, by Robert Angus Smith, is entitled Air and Rain: The Beginnings of a Chemical Climatology (see Figure 1). This book focused on measurements taken in England with some reports from western Europe taken in the 1850s. Smith, in addition to introducing the term "acid rain," showed that precipitation chemistry is quite variable and that there are differences between industrial-urban, rural and sea coastal regions. Owing to the little documentation of the analytical methods employed, the data presented in this publication are difficult to compare with current values.

In the 1940s, meteorologists became very interested in precipitation chemistry with a view toward explaining the origin of the atmospheric particles used to form raindrops and snowflakes. This major effort to monitor the chemistry of rain and snow was undertaken in the Scandinavian countries as a joint research program between meteorologists and agriculturalists. In the 1950s a network was established in this country with resources from the U.S. Air Force, but for only one fiscal year. The data from this sample collection effort between July 1955 and June 1956 are often referred to as the "Junge" data after the principal scientist, Dr. Chris Junge. The network shown in Figure 2 was comprised of sites largely located at weather observing stations of the U.S. Weather Bureau. The first description of the nation's precipitation chemistry characterization were obtained from this data set.

Subsequently, a national network was initiated by the U.S. Public Health Service (and the National Center for Atmospheric Research). This somewhat smaller national network was operated between 1960 and 1966. As shown in Figure 3, some of the same stations used for the 1955-1956 network also served this network, but important new stations were added near urban centers. These data are suspect owing to a lack of confidence that the cover over the wet-only collector sealed adequately against wind-blown local dust and other contamination.

Throughout the time frame from the 1800s through the late 1900s, aporadic measurements of precipitation chemistry have been undertaken at individual sites as well as certain network operations for specific purposes. Much of the sporadic sampling was conducted in agricultural research stations for purposes of assessing the value of the precipitation chemistry for crop development. Two examples of such activities are the sulfur analyses for 1913 to 1919 reported by the University of Illinois Agricultural Experiment Station in 1920 and the St. Louis Metropolitan Meteorological Experiment network data for 1971 to 1975.

The 1920s data shown in Figure 4 gave an average annual sulfur deposition of 50.5 kg ha^{-1} (45.1 lbs $acre^{-1}$) and this value compares with the current annual average of 23.3 kg ha^{-1}. These values for Illinois are representative of the region encompassing the eastern U.S. as we will see later.

The St. Louis study showed great variability within a 2,400 km^2 area over and downwind of the city. Values of acidity ranged from less than 4.5 pH near industrialized areas to greater than 6.0 pH at many urban and rural sites.

The single longest continuing record in this country is the Hubbard Brook site in New Hampshire which has been in operation since 1963.

Network Operations

This leads me to a brief recounting of the networks that are currently in operation. At last count about 71 recent-past and current monitoring efforts have been identified in Canada, Mexico and the United States. The largest of these is the network operated by the National Atmospheric Deposition Program which currently includes 116 stations shown in Figure 6. The network was initiated in 1978 with 16 stations and now extends from American Samoa to Maine and from Alaska to Florida. A cooperative effort with Canada involves operation of three of these stations across the border. This network will form the core of the National Trends Network being implemented by the USGS as a task set forth by the federal Interagency Task Force on Acidic Precipitation.

A longer operating network is the Multi-state Atmospheric Power Production Pollution Study (MAP3S) network begun by the Department of Energy and currently is a cooperative effort with EPA. This network also seen in Figure 6 began with four stations in 1976 with four added in 1978. The MAP3S network is different from the NADP in that event samples are collected as opposed to the weekly samples of the much larger national NADP/NTN.

I do not intend to describe for you all of the various monitoring networks that either were recently operated or are currently in use. I encourage you to read Wisniewski and Kinsman (Bulletin American Meteorological Society, Vol. 63, pp. 598-618, 1982) for further information.

SAMPLE COLLECTION, HANDLING AND ANALYSIS

Sample Collection

Scientists collecting precipitation samples have used almost anything that one can imagine. This "anything" covers the range from glass bottles (both clear and darkened) to baby bottle plastic liners. In Figure 7 a laundry basket is shown staked to the ground and supplied with a clean polyethylene liner for precipitation collection. The nearness of the opening to the ground invites contamination of samples from wind-blown material. An improvement of this concept is shown in Figure 8. The lower half of a polyethylene bottle is secured by means of hose clamps to a common fence post about 1 m above ground. Prior to a precipitation event, a clean bottle of

slightly smaller diameter with a fitted polyethylene liner is placed in the holder. The entire bottle with liner and sample is transported to the laboratory. The sample is removed, a new liner inserted, and the bottle is returned for re-use in the field. For analyses that require very large samples, an entire roof top shown in Figure 9 was carefully covered with polyethylene and used as the collection surface. Such a large area also increases contamination risk from dry deposition, wind-raised foreign material and birds. An example of a sequential collection is shown in Figure 10. A number of such devices have been built, but all of them are directed toward acquiring one sample after another during a single rain event. There are means to control the sample collection by either the volume or time interval and some devices incorporate both features. The most widely deployed sample collection equipment is shown in Figure 11. A precipitation-sensitive switch is used to activate a motor to uncover and cover the wet-side bucket collector. The dry-side bucket is exposed to dry deposition during non-precipitating periods. This type of collector is currently used for the NADP/NTN and MAP3S networks. Obviously, the quality of the chemical analysis is highly dependent upon the quality of the sample collecting vessel. I recall a project in which the investigator thought it would be cost-saving to use the existing weighing-bucket raingage network to collect samples for trace metal analysis. Unfortunately, zinc was one of the metals of great interest for this particular project and most weighing-bucket raingages use a zinc-coated pail. As a result the entire effort was wasted, but a valuable lesson was learned. The type of collecting vessel is somewhat determined by the <u>goal</u> of a particular sampling program.

Anyone wishing to collect rain or snow samples for chemical analysis is cautioned to first check the collection vessel for the chemicals of interest, to see if, in fact, the analysis will be contaminated.

A second serious consideration is whether one wishes to collect a bulk sample as opposed to a wet-only sample. A bulk sample is one which is directly exposed to the atmosphere and remains open throughout a prescribed interval of time. This is not a very satisfactory way of collecting precipitation samples because of the natural tendency of birds to light on the rim of the collector always facing outward contributing to the debris deposited inside of the container. In addition, dust, leaves and other natural materials are likely to enter the sampler and contaminate the precipitation in an unknown way.

The interval between the collection of samples is also largely determined by the goals for the sampling program. If one wants to study the effects of precipitation chemistry on the forest, for example, it is highly unlikely that it is necessary to collect samples on intervals of anything less than a one-week period and perhaps even one month may suffice for the majority of biological effects studies. On the other hand, if one wants to study the variability of precipitation chemistry in convective storms during the warm season, a sequential sampler may be necessary to obtain samples as frequently as one or more per minute. So in establishing a sampling program it is most important to carefully consider the <u>goal</u> of that program and then determine the need for event as opposed to less costly, longer period sampling to achieve that goal. The NADP/NTN weekly collection network is an arbitration between event samples and monthly samples with the program goals to determine the long-term trend of precipitation chemistry and atmospheric deposition effects on the environment.

Sample Handling

Once a sample has been confined within the collecting vessel the safest thing is to immediately seal that vessel and carry it or ship it to the analytical laboratory. However, it is a practice in some operations to allow prior handling of the sample such as withdrawal of aliquots for the local determination of a particular parameter. For example, the NADP allows extraction of a few milliliters for the field determination of pH and conductivity. Immediately after the aliquot has been withdrawn, the sample is sealed and then shipped to a central laboratory for further chemical analysis. Shipment of the sample is an important consideration for any type of sampling program since one must be sure that the collecting vessel does not leak in transit.

Sample Analysis .

Written documentation of everything concerning the sample up to this point should be provided for the laboratory staff as the analysis of precipitation chemistry proceeds. Certainly, any laboratory, whether it is adjacent to the sampling site or several thousands of kilometers distant, should have certain analytical capabilities for the determination of trace materials in precipitation. The analysts must be trained to recognize the expected concentrations in precipitation and detect contamination in a sample. Contamination can originate from either natural causes or handling of the sample.

And finally, one must be alert that even though a determination may be perfectly accurate and within statistically allowable errors of the instrumentation, the value may, in fact, be excluded from a data set for other reasons. For example, a loose covering over the collection vessel can allow crustal dust to enter into the collector during non-precipitating intervals and can artifically raise the concentrations of those materials. A "leaky" seal results in values that are not representative of precipitation but are more representative of a bulk sample. The major point is that the sample quality control does not begin or end in the laboratory but must be extended to include everything from the sample collection in the field to the point of preparing the data for dissemination or further interpretation and archiving.

Concern has been expressed about the chemical integrity of samples collected less frequently than the duration of a single storm. There is reason for some scientific inquiry on this matter, but the available data suggest that any chemical changes in a sample will occur in a relatively brief period after the precipitation has ended. However, event samples may not be any more stable than weekly samples if the delay between the collection of the sample and its analysis is of the order of one or more days. Consequently, until real-time chemical analysis can be performed in the field, all currently available data contain a largely unknown contribution from this effect.

SELECTED INTERPRETIVE ANALYSES

Precipitation-Weighted Average pH

And now, having said all of this, I would like to share with you some analyses of the NADP network data that are currently archived in the EPA data files. The first series of maps illustrates the changing pattern of pH

distribution as additional stations were added to the network during 1979 to 1981. Figure 12 shows the first set of data for 1979 from the NADP network and Figure 15 indicates the most recently available pH map showing how the variability has apparently increased in the western states due to the siting of additional stations. The gradual increase of the number of samples at each site used ot obtain the precipitation-weighted average has produced little change in the northeast U.S. pH pattern. This is easily seen by comparing Figures 12, 13, 14 and 15. A graphical differential analysis of the patterns shown in Figures 12 and 15 reveals only random differences of $\pm$ 0.1 pH units in the region from Illinois eastward and from Tennessee northward.

Total and Specific Ion Concentrations

An attempt has been made to identify those cations and anions that contribute most to the total ion loading in precipitation over the United States. The dominating feature of the average monthly total ion concentration shown in Figure 16 is a relative high located over southern Ontario north of Lakes Erie and Ontario and extending northeast along the St. Lawrence Valley. Across Illinois, along the Ohio River Valley and extending into New England, typical values are 200 $\mu eq\ L^{-1}$ with a slight increase toward Nova Scotia. The Great Plains and the front range of the Rocky Mountains in the U.S. show values of about 150 $\mu eq\ L^{-1}$, and there is a relative minimum over Idaho, Washington and Oregon.

It is interesting to note that the maximum concentrations are displaced slightly to the northeast of the commonly perceived maximum emissions region of the industrialized Ohio River Valley. The immediate inclination is to interpret this pattern as a downwind displacement due to the mean flow pattern. However, the distribution seems to suggest that wet deposition maximums occur in close proximity to source regions.

The average chloride concentrations show the largest values along the eastern and western coastal areas (see Figure 17). These concentrations appear to maximize along those respective coastline areas where major synoptic storm systems frequently enter the continent from the west or move northward along the eastern seaboard. Whether this observation can be borne out by relating seasonal patterns in coastal storm tracks to chloride concentrations has yet to be determined. Minimum values of chloride are observed through the central, south and western United States, as well as most of Canada. The sodium ion shows an identical pattern to chloride emphasizing the oceanic influence on the concentration pattern for these ions. The dashed lines in Figure 17-22 indicate the percentage of the total ion concentration attributed to the individual ions.

The calcium ion concentration distribution in Figure 18 shows minimum values along the coasts and maximum values over the continent. A maximum in the western provinces of Canada extends through the Great Plains into a second maximum in west Texas, southern Arizona and New Mexico. The Great Plains maximum appears to be associated with the semi-arid agricultural practices of that area.

Stations in South Dakota, Nebraska and southern Minnesota show ammonium concentrations of greater than 40 μeq L^{-1}, and equally high values were also observed over extreme southern Ontario (see Figure 19). The relative contribution of the ammonium to the ion total shows a clearly distinguishable maximum in excess of 35 percent over South Dakota and Nebraska.

It is speculated that the observed maximum ammonium concentration values can be attributed to certain types of farming activities such as cattle feed lot operations. In certain other areas, perhaps ammonium-bearing fertilizers may contribute during certain seasons of the year. It is important to extend this analysis to individual seasons to explore possible explanations for these observations.

The nitrate concentration distribution in Figure 20 shows the interesting fact that values greater than 20 μeq L^{--1} extend along an axis from the extreme southwestern U.S. toward the northeast across the entire continent. Within that broad area of relatively high cncentrations, two maximums are observed. The first is over south-central California and the second and larger maximum extends northeastward over lower Ontario. The Gulf Coast region from Texas to Florida shows very little nitrate in precipitation.

Sulfate ion concentration distribution is dominated by a large maximum over the entire eastern U.S. and southeastern Canada (see Figure 21). The high center is located over southern Ontario and extends to the northeast along the St. Lawrence Valley. Concentrations in excess of 40 μeq L^{-1} occur from lower James Bay to Minnesota, southward to Oklahoma, southeastward to central Georgia, and then off the Carolina coast. Two other areas with 40 μeq L^{-1} are observed, one over the western provinces of Canada including British Columbia and one over southern Arizona. In an analysis not presented in this paper, it was found that sulfate was the largest contributor to the total ion concentration over nearly all of North America, and where it was not largest, it was either second or third largest.

Finally, the hydrogen ion concentrations obtained from measurements of precipitation pH show maximum values over the Ohio River Valley and northeastward into northern New York and Vermont (see Figure 22). Values in excess of 25 μeq L^{-1} (i.e., pH < 4.6) are observed in an area bounded by a line extending southwestward from Newfoundland to Lake Superior, south to northeast Arkansas, and southeastward to the Atlantic Ocean. The maximum concentrations of nitrate and sulfate are located in southern Ontario and north of Lakes Erie and Ontario, but the maximum hydrogen concentrations are nearly totally confined to the U.S. from Indiana through Ohio, Pennsylvania and New York.

Among the principal features of the several distributions are (1) the sea salt constituents, sodium and chloride, exhibited relative maximums along the east and west coastal regions of North America; (2) elements commonly associated with crustal dust, that is, calcium and magnesium, maximized in the continental interior; (3) a relative ammonium maximum seen in the central Great Plains may be associated with particular agricultural practices in that area; and (4) those ions of most concern to air quality and acidic precipitation considerations maximize in the industrialized east with the sulfate and nitrate maximums in southern Ontario paralleling the St. Lawrence Valley and the hydrogen maximum over the Ohio River Valley.

Precipitation Chemistry Characterization

In an effort to further simplify the characterization of precipitation chemistry over the eastern U.S., the four ions contributing the greatest percentage to the total ion concentration were selected from each station. In general, the top four ions at any one station accounted for about 90 percent of the total. From the previously presented data, it is readily seen that sulfate and hydrogen together account for 60 to 70 percent of the total ion concentration in the eastern states. If nitrate is added to these two, the total is raised to about 75 percent over much of the northeast. The addition of a fourth ion depends on the region under consideration and is quite variable. The regional characterization of precipitation chemistry by four ions is shown in Figure 23. The largest area of the eastern U.S. is characterized by hydrogen ion, sulfate, nitrate and ammonium, in that order. This area encompasses Wisconsin, most of Michigan, Illinois, Indiana, Ohio, western Pennslyvania, most of New York, and into the southern states of Kentucky, western Tennessee, and parts of Mississippi and Alabama. If ammonium is replaced with calcium, an additional area encompassing Ontario, southern Quebec and a small portion of eastern Tennessee is included. Through Vermont, New Hampshire, western Maine, a small portion of the Carolinas, northern Georgia and the Gulf coastal states of Mississippi, Alabama and Florida the calcium or ammonium is replaced with sodium. In this region, hydrogen, sulfate, nitrate and sodium account for nearly 90 percent of the total ion concentration. Finally, sodium, chloride, hydrogen and sulfate ions dominate the east coastal areas.

Ion Ratio Analysis

The ratio of hydrogen to the sum of sulfate and nitrate (all expressed in microequivalents per liter) is indicative of possible chemical forms responsible for the observed concentrations. For example, if all of the hydrogen ion came from the presence of sulfuric and nitric acids the ratio would be one. The maximum ratio of about 0.6 shown in Figure 24 extends along the Ohio River Valley northeastward into southern Maine. The distribution of this ratio suggests a large fraction of the total sulfate and nitrate concentration is associated with non-acidic compounds.

Application of the same calculation with ammonium as the numerator suggests a relative abundance of ammonium sulfate and/or ammonium nitrate in the Great Plains (see Figure 25). Ratios in excess of 0.4 are observed in central California northward to central Washington. Most of the northeast U.S. is characterized by ratios less than 0.2.

The ration of calcium to the sulfate and nitrate sum is shown in Figure 26. Similar to the ammonium ratios, values less than 0.2 dominate in the northeastern states. A relative maximum is observed over the central Great Plains with ratios exceeding 0.8 seen over the Great Basin.

These three ratio maps suggest the following: 1) the east is dominated by high ratios of hydrogen to the sum of sulfate and nitrate possibly related by fossil fuel consumption; 2) the Great Plains are dominated by large ammonium to the sum of sulfate and nitrate ratios, perhaps associated with

agricultural practices; and 3) the Great Basin and secondarily the Great Plains show high ratios of calcium to the sum of sulfate and nitrate likely associated with crustal dust material. Further research into ratios may lead to a better understanding of sources for the observed precipitation chemistry.

Trend of pH

A final word about trends of the chemical components in precipitation. As mentioned earlier in this presentation, there are no long-term continuous measurements available to determine a regional trend. The Hubbard Brook, New Hampshire station shows a rather steady decline of sulfate since measurements began in the early 1960s with little detectable trend in nitrate. To translate these data to discuss trends over a region is very misleading and should be avoided.

Much concern has been expressed over a perceived trend toward increasing acidity based on data obtained in 1955-1956, 1960-1966 and 1972-1973. Unfortunately, the key data that determine the trend, the 1955-1956 period, were modified by crustal dust associated with a large scale drought.

The measurement of pH was not considered in the analysis protocol of this early data set, but estimated values were calculated by means of an ion-balanced equation. The calculated distribution of pH for 1955-1956 is shown in Figure 27.

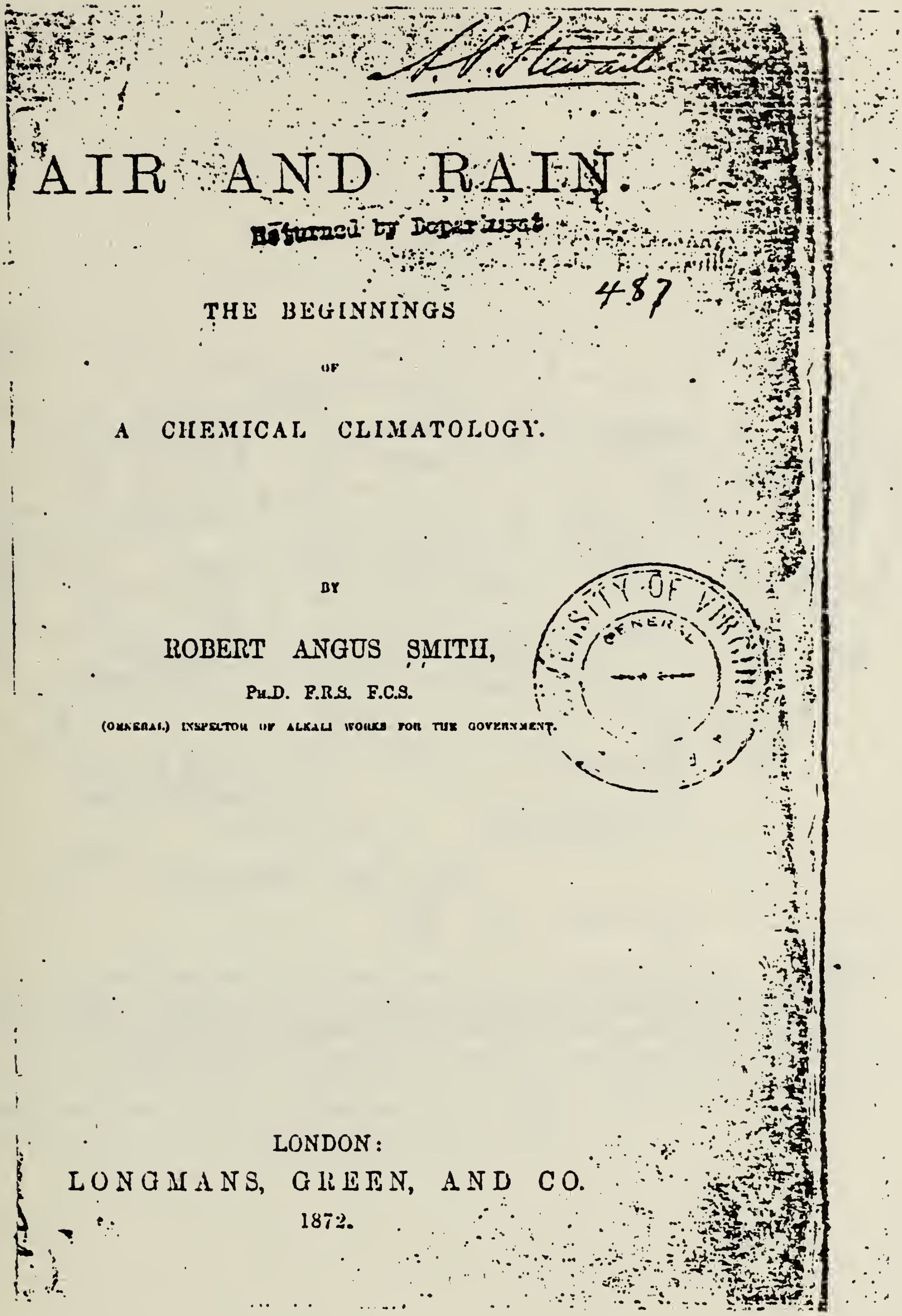
When reasonable mathematical adjustments to the crustal dust-contaminated chemistry are made, the acidity increases to values comparable to currently observed values. Selected isopleths of the recalculated pH are shown as dashed lines in Figure 28. The solid lines represent the precipitation-weighted average pH for samples from the NADP network through June 1980. Focusing on the pH = 4.4 isopleth in the northeast U.S. one can readily observe reasonable agreement between the adjusted 1955-1956 data and the currently obtained average values. Therefore, there does not appear to be a discernible increase of acidity of precipitation in the eastern U.S. within the limitations of available data.

SUMMARY

In summary, I have tried to emphasize the complexity of sampling and analyzing precipitation samples and I believe many of the problems have been overcome with present-day technology. The problems enumerated cast doubt on the utility of past data for shedding light on current acidic precipitation research.

I have also emphasized the nearly complete lack of a precipitation chemistry data base prior to 1979. Any determination of a trend using sporadically obtained data prior to 1979 becomes speculation and is subject to additional interpretation.

Lastly, I have tried to share with you some recent findgs from the rapidly increasing national data base. The length of record is still inadequate to describe the precipitation chemistry from a climatological point of view. The natural variability of air motions, pollutant loading, and precipitation is continuing to influence the stabilization of mean acid deposition values. The monitoring program the U.S. has initiated is critical to a better understanding of the acid deposition phenomenon and, by 1989, the 10-year data base will permit a much firmer assessment of the issues surrounding changing precipitation chemical quality and its environmental consequences.



AIR AND RAIN.

Returned by Department

487

THE BEGINNINGS

OF

A CHEMICAL CLIMATOLOGY.

BY

ROBERT ANGUS SMITH,

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LONDON:

LONGMANS, GREEN, AND CO.

1872.

Figure 1. The cover page from the earliest comprehensive report on precipitation chemistry by R.A. Smith in 1872. Smith used the term "acid rain" in this work.

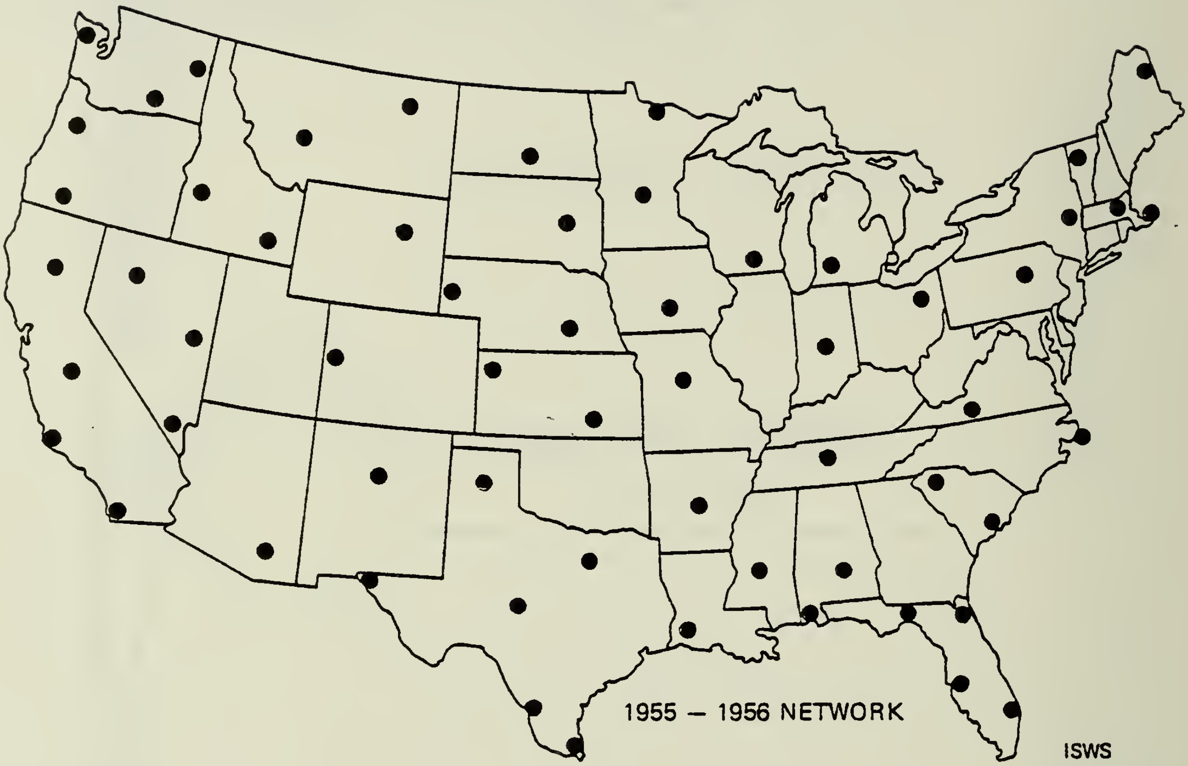

Figure 2. The 1955-1956 network of precipitation samplers used by Dr. C.E. Junge and sponsored by the U.S. Air Force. These sites were largely located at first-order weather stations.

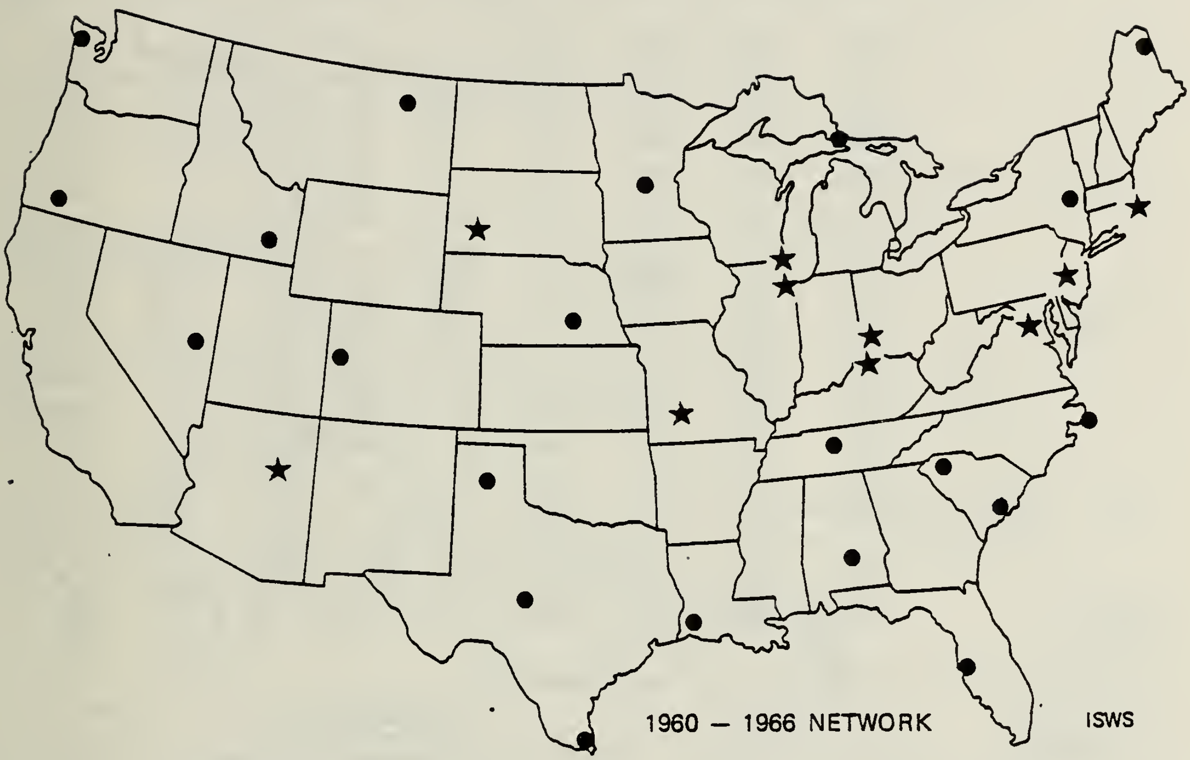

Figure 3. The 1960-1966 Network of precipitation samplers operated by the U.S. Public Health Service and later in the period by the National Center for Atmospheric Research. The closed circles are stations previously used in the Junge network (figure 2) and the stars represent new stations initiated for this network.

SULFUR ADDED TO THE SOIL BY RAINFALL:
ILLINOIS EXPERIMENTS (Amounts expressed in pounds per acre)

Month	1913	1914	1915	1916	1917	1918	1919	Avg
JAN	4.3	2.9	5.8	7.5	3.7	3.5	4.2	4.6
FEB	2.7	6.9	3.4	2.7	3.3	6.0	5.1	4.3
MAR	4.5	4.0	4.0	4.7	5.1	3.7	(1)	4.3
APR	4.1	4.2	3.0	4.6	5.0	6.0	3.2	4.3
MAY	1.6	2.2	5.1	8.6	5.6	4.8	5.8	4.8
JUN	2.6	2.7	3.3	5.2	4.6	4.3	4.5	3.9
JUL	2.0	2.0	4.4	1.9	3.1	2.2	1.8	2.5
AUG	2.0	5.7	4.1	2.0	4.3	4.7	4.7	3.9
SEP	3.3	3.0	3.0	2.3	2.5	3.4	3.0	2.9
OCT	5.1	3.0	1.6	5.0	4.9	5.8	2.9	4.0
NOV	4.4	2.4	2.5	3.1	3.9	2.4	3.0	3.1
DEC	3.4	1.6	5.4	3.3	1.7	0.7	1.6	2.5
Total	40.0	40.5	45.5	51.0	47.7	47.6	39.8[1]	45.1
Average	3.3	3.4	3.8	4.3	4.0	4.0	3.6	3.8

(1) No record of March rainfall

Figure 4. The deposition of sulfur at Champaign, Illinois by month for the period 1913 through 1919. The average annual value of 45.1 lbs acre^{-1} (50.5 kg ha^{-1})is about twice the current average value of 23.3 kg ha^{-1} obtained for the years 1979 through 1981. These data are from Bulletin 227, University of Illinois Agricultural Experiment Station, Urbana, June 1920.

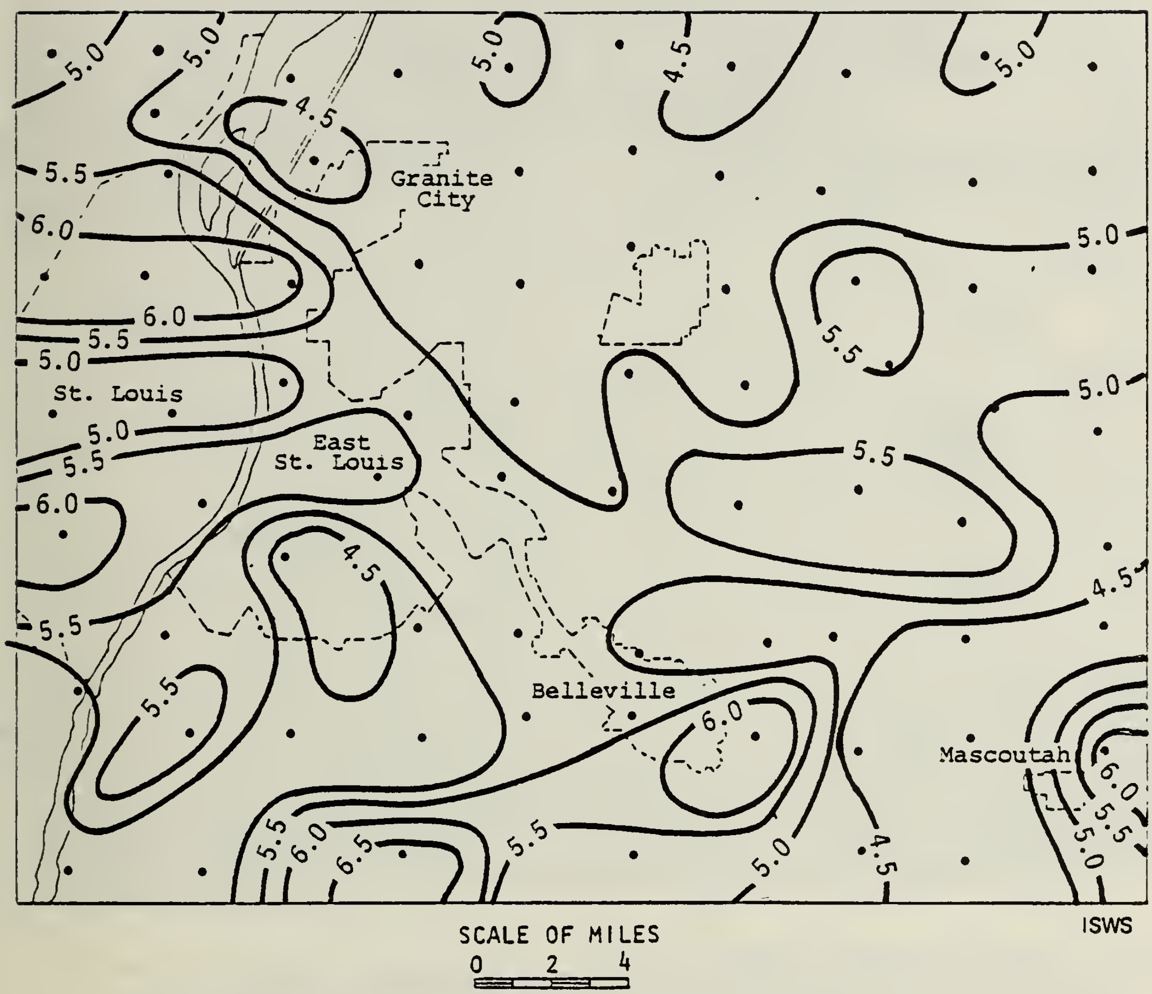

Figure 5. An example of the spatial variability of pH over an area of about 2400 km^2 near St. Louis, Missouri. The pH varied from 4.3 to 6.2 across southern E. St. Louis west to St. Louis over a distance of only 10 km. The values are precipitation-weighted average of 25 convective storms during summer, 1972.

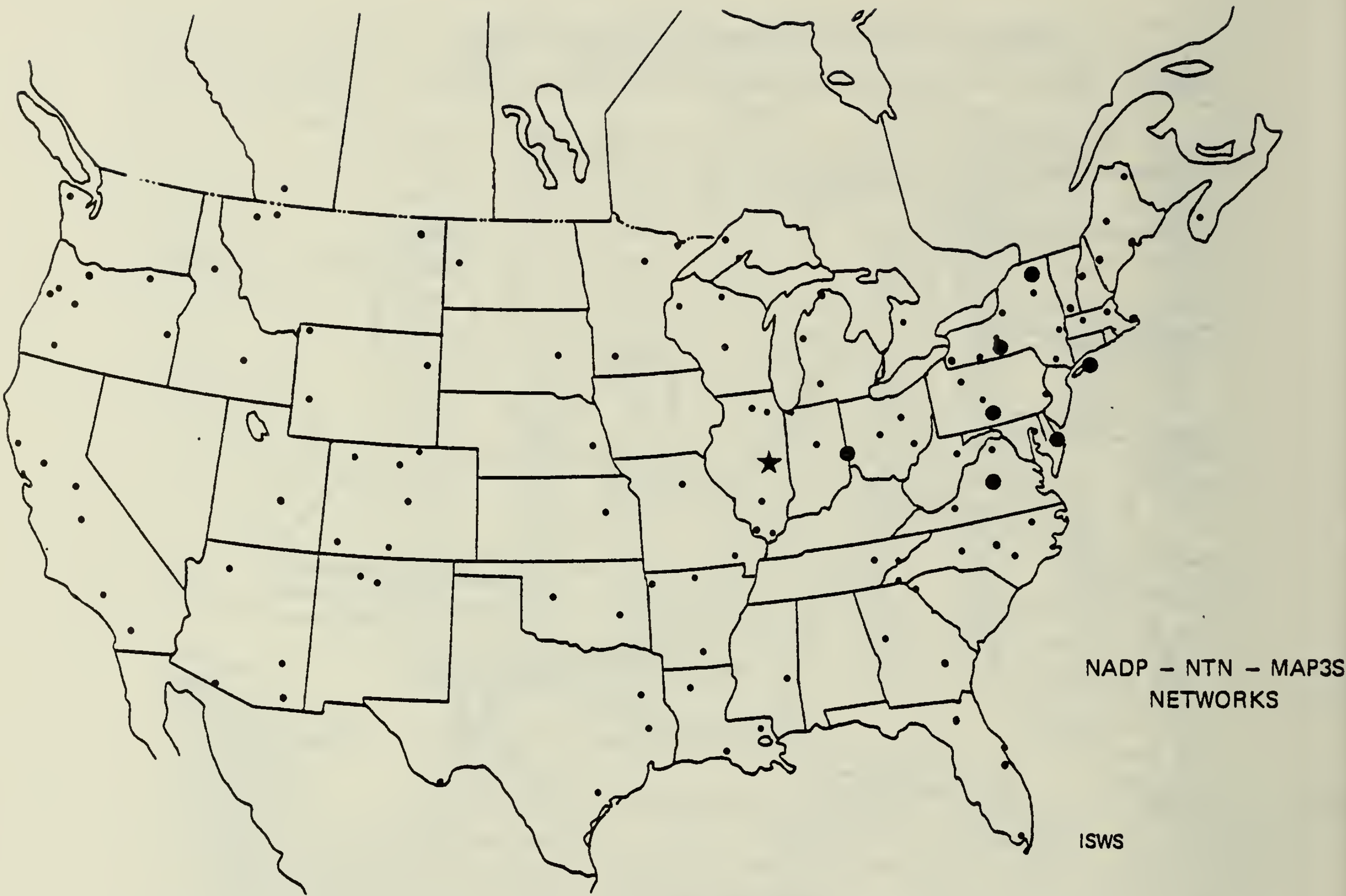

Figure 6. The currently operating National Atmospheric Deposition Program/National Trends Network/Multistate Atmospheric Power Production Pollution Study precipitation sampling sites. The solid circles are the MAP3S event sampler locations. The star indicates a site where both event and weekly samples are collected. The map is correct as of July 1983.

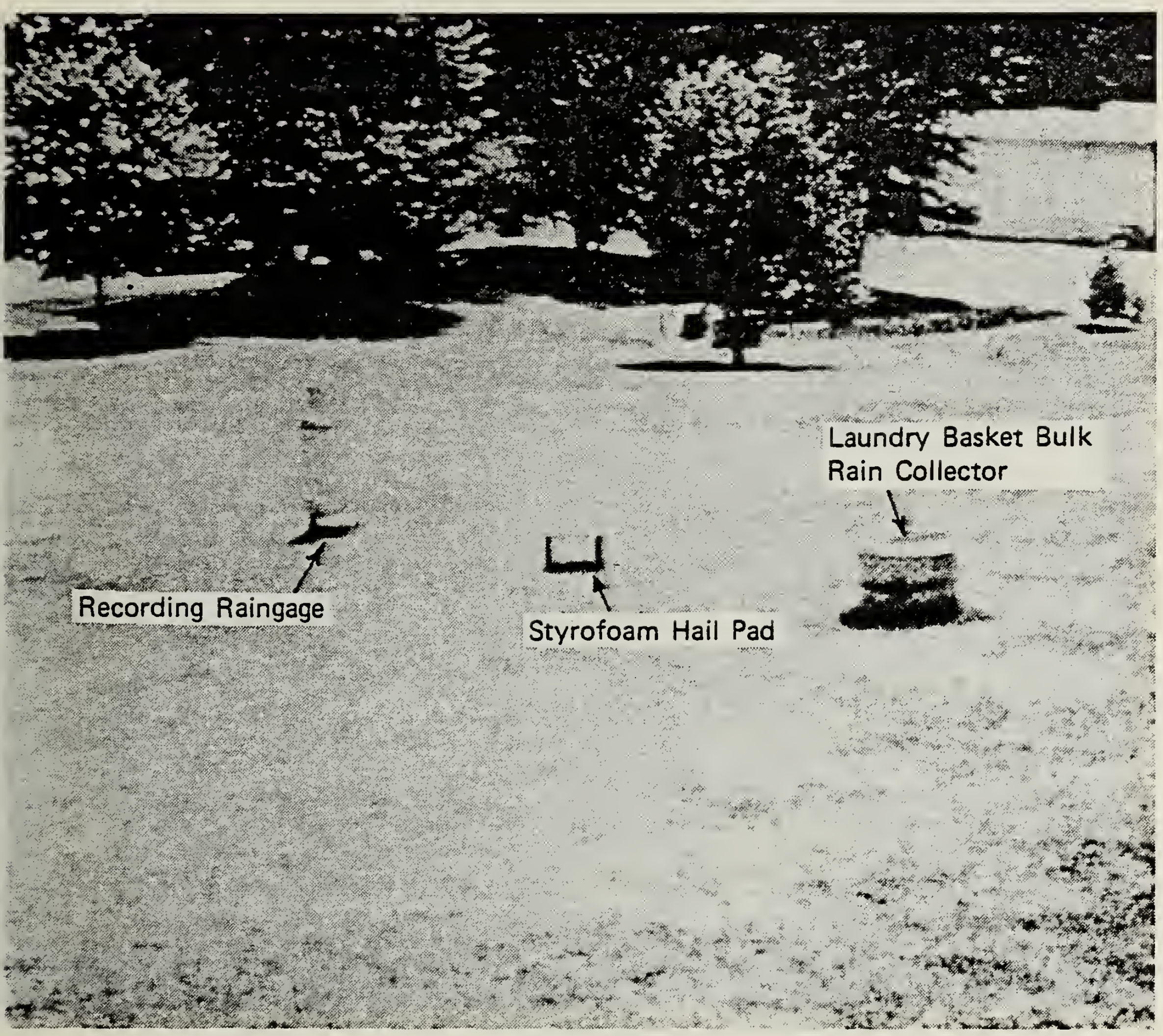

Figure 7. A bulk precipitation sampler (laundry basket) used for precipitation chemistry studies in Illinois 1969-1971. The basket was lined with a polyethylene bag which was removed after an event.

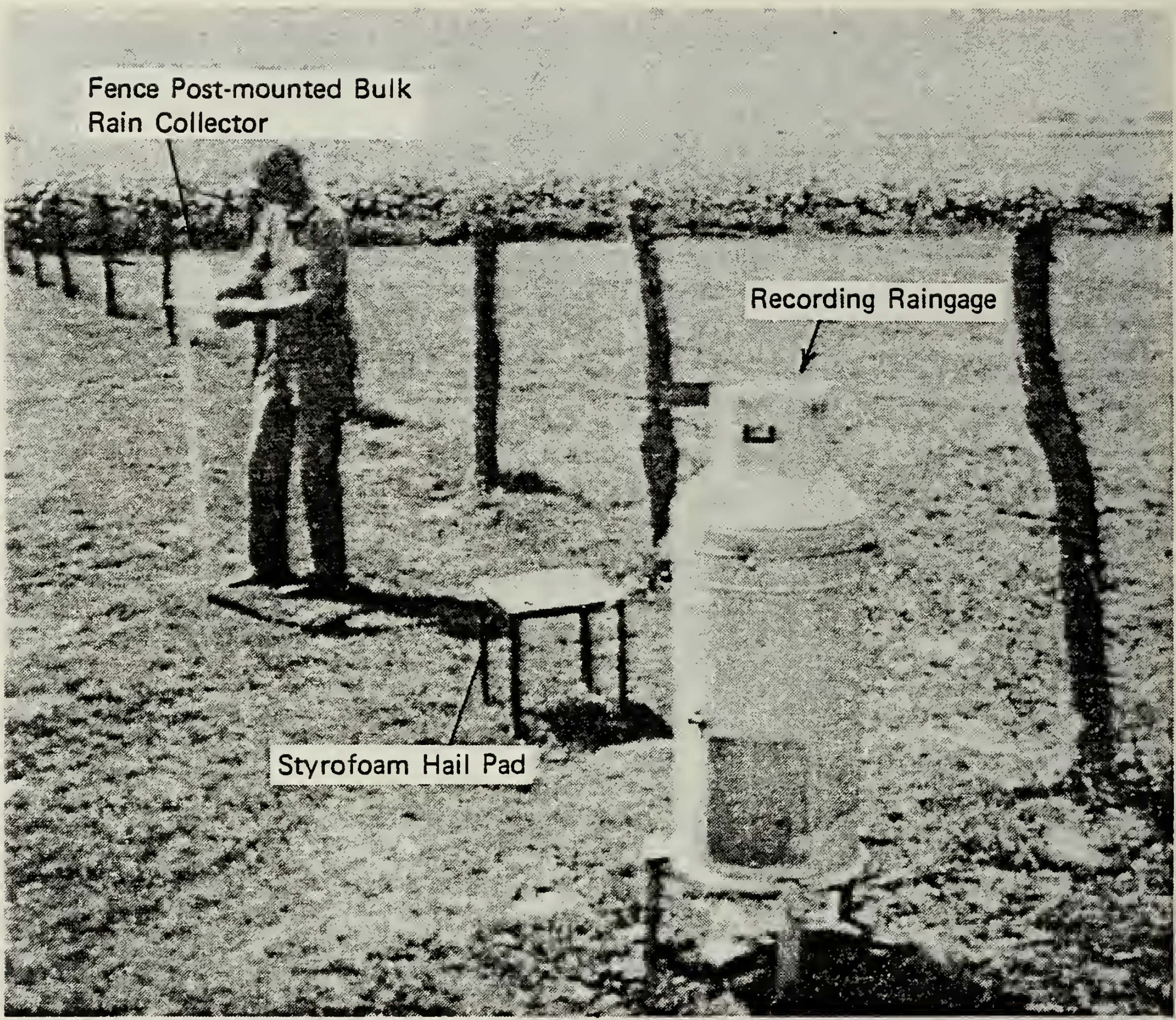

Figure 8. A polyurethane bottle used for sample collection in the St. Louis, Missouri network 1972-1975. The bottle was installed on a fence post to inhibit near-surface wind-blown material entering the collector. The bottles were placed in the holder in the morning and retrieved immediately after an event to minimize dry deposition collection.

Figure 9. A roof top lined with polyethylene to collect large volumes of water for sensitive analyses of radioactive materials. This form of collection is nearly useless for pollutant wet deposition studies because of the large area exposed to dry deposition.

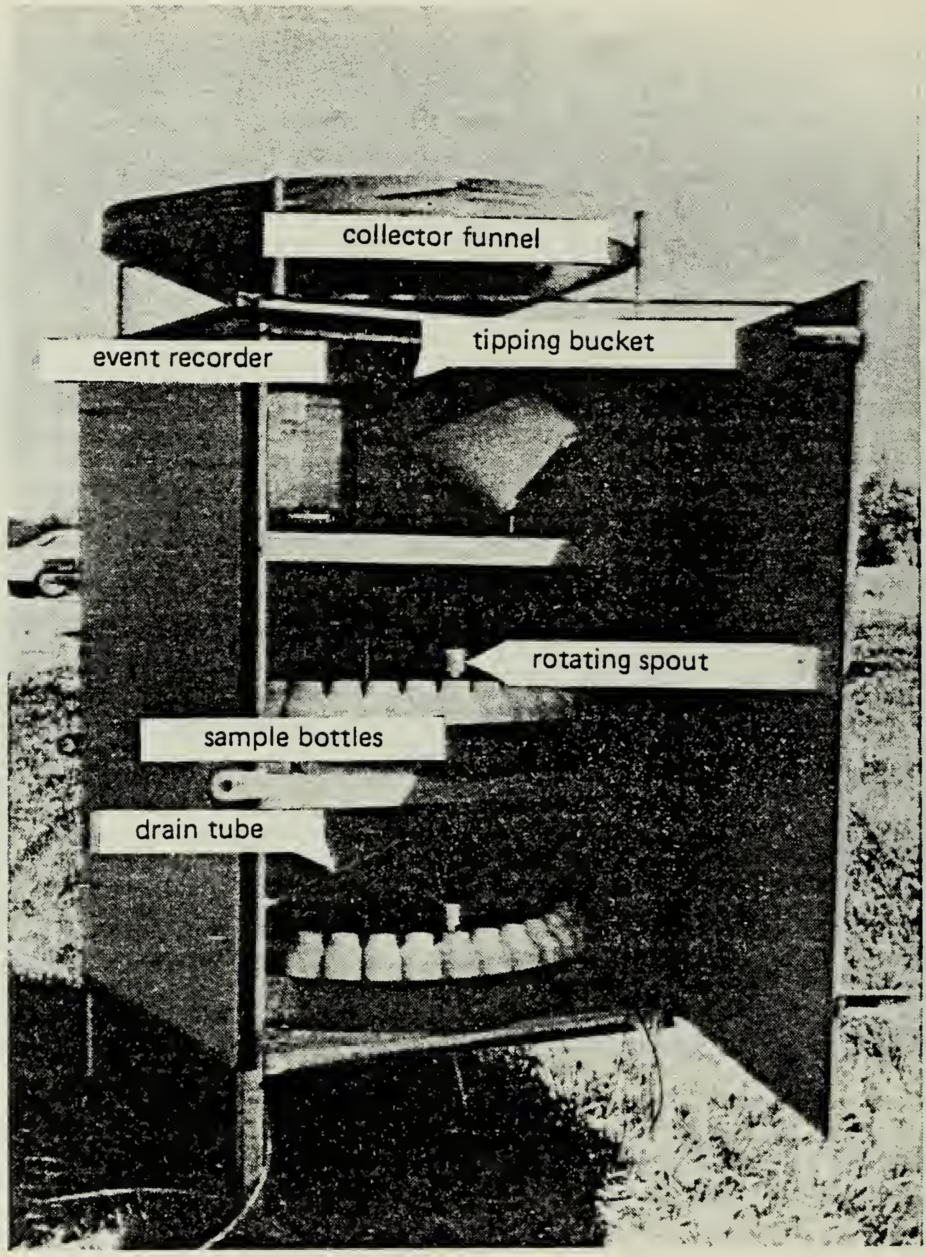

Figure 10. A sequential sampler designed to collect a given volume of precipitation in individual bottles. The rate of bottle usage was determined by the precipitation rate. Later versions allow the operator to specify time intervals between bottle collections.

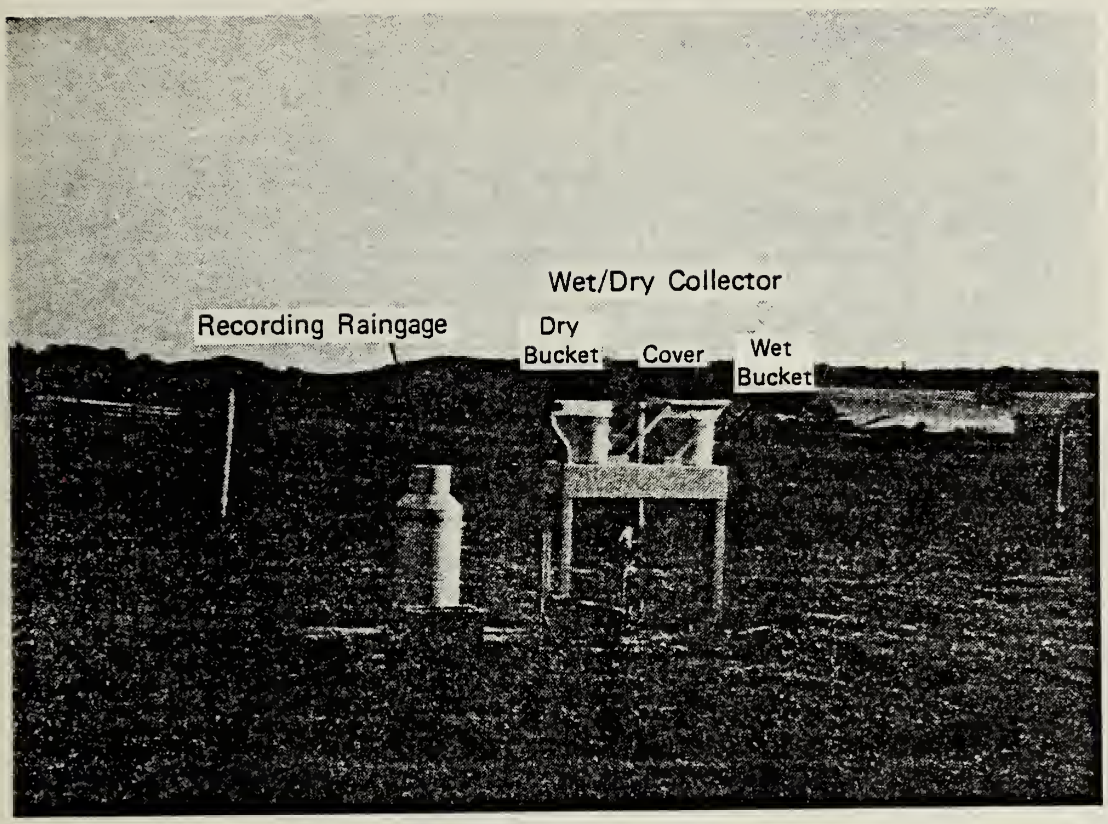

Figure 11. The currently used wet/dry sampler considered standard equipment for the NADP/NTN and MAP3S networks. The covered bucket collector minimizes deposition of dry material between precipitation events. A precipitation-activated motor uncovers the wet side and covers the otherwise exposed dry bucket collector. After a precipitation event the cover returns to seal the sample in the wet bucket collector.

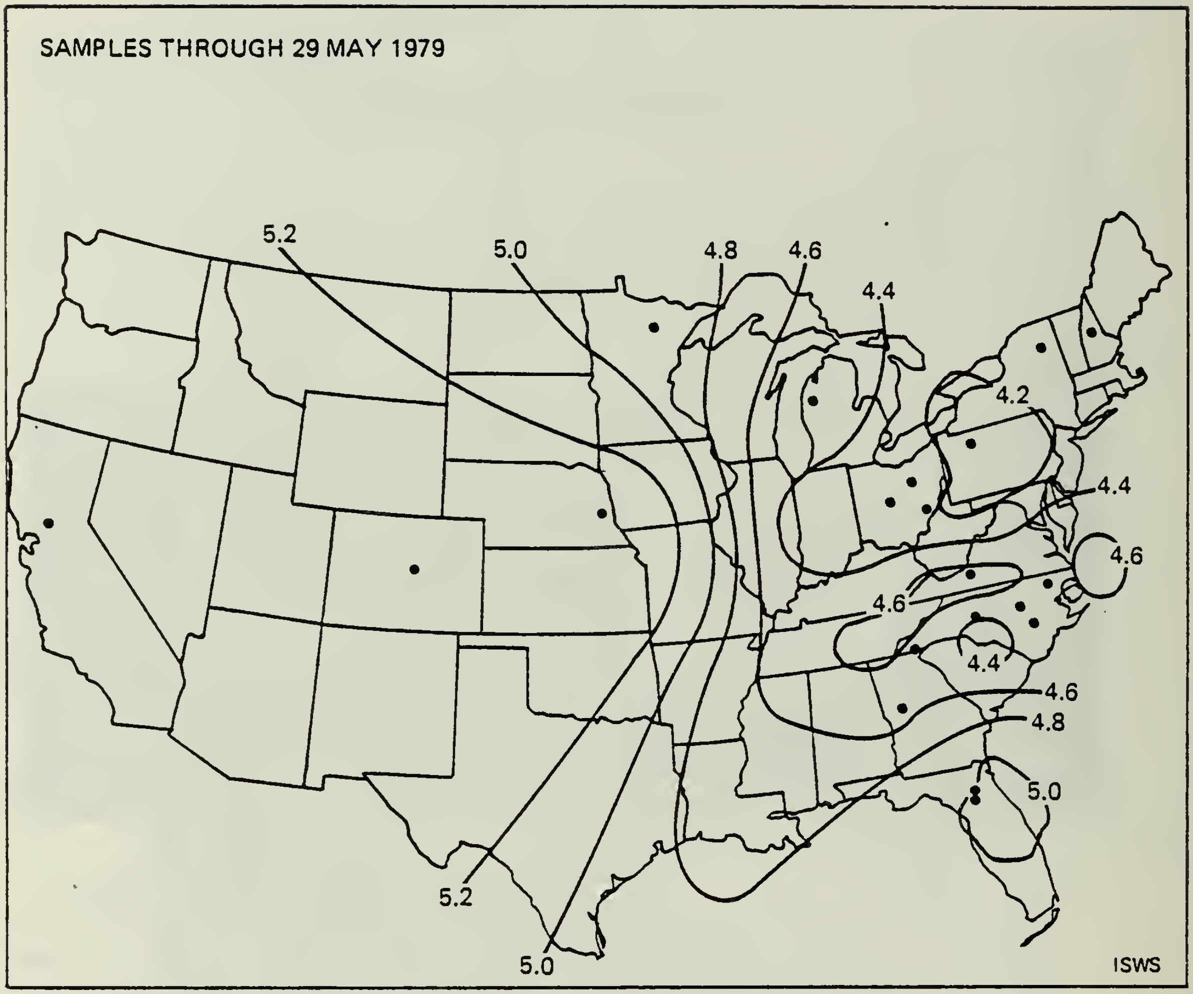

Figure 12. The precipitation-weighted average pH obtained from all available samples in the NADP network through May 29, 1979. The closed circles in this map and on those that follow indicate stations where samples were included to define the isopleths. Note the position of the pH = 4.4 isopleth and the absence of a pattern in the west.

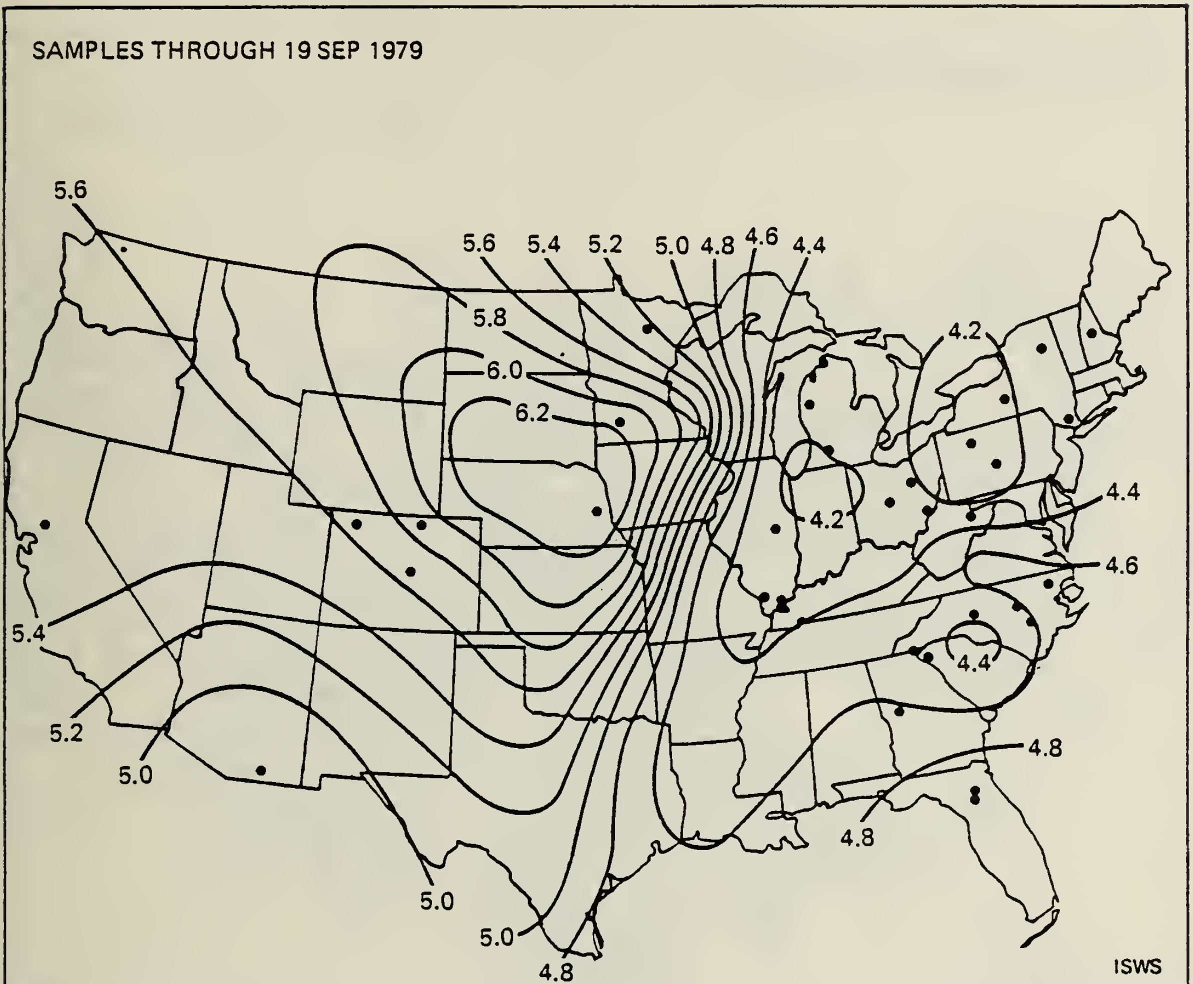

Figure 13. The same as figure 12, but includes samples through September 19, 1979 and additional stations. More pattern definition is achieved with additional stations in the west. The pH = 4.4 isopleth has shifted slightly through Illinois in response to more data in western lower Michigan and southern Illinois.

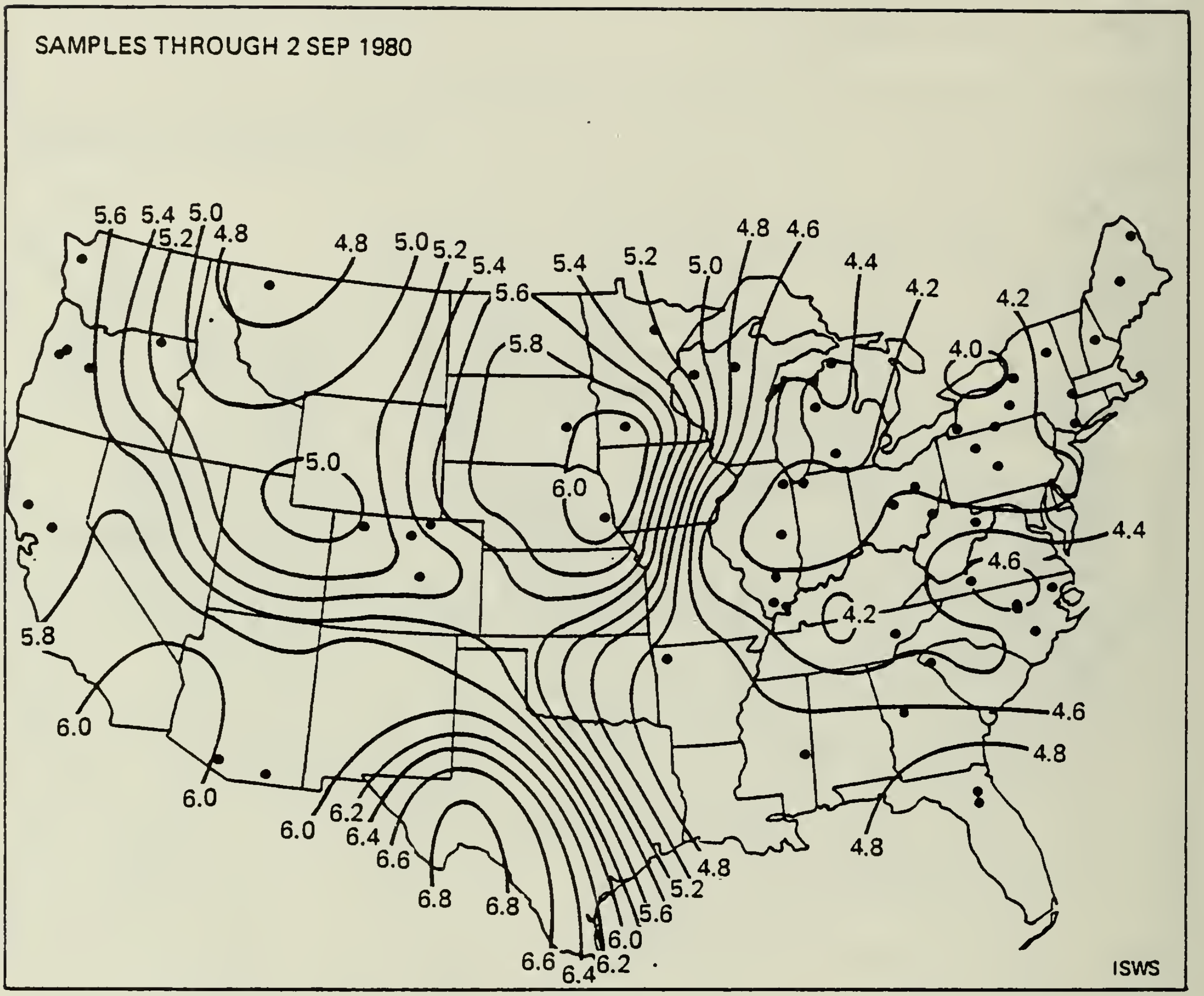

Figure 14. The same as figure 12, but includes samples through September 2, 1980 and additional stations. Minor changes of the pattern in the northeast U.S. can be seen as well as in the north-central Great Plains where values of pH $\geq$ 6.0 are observed.

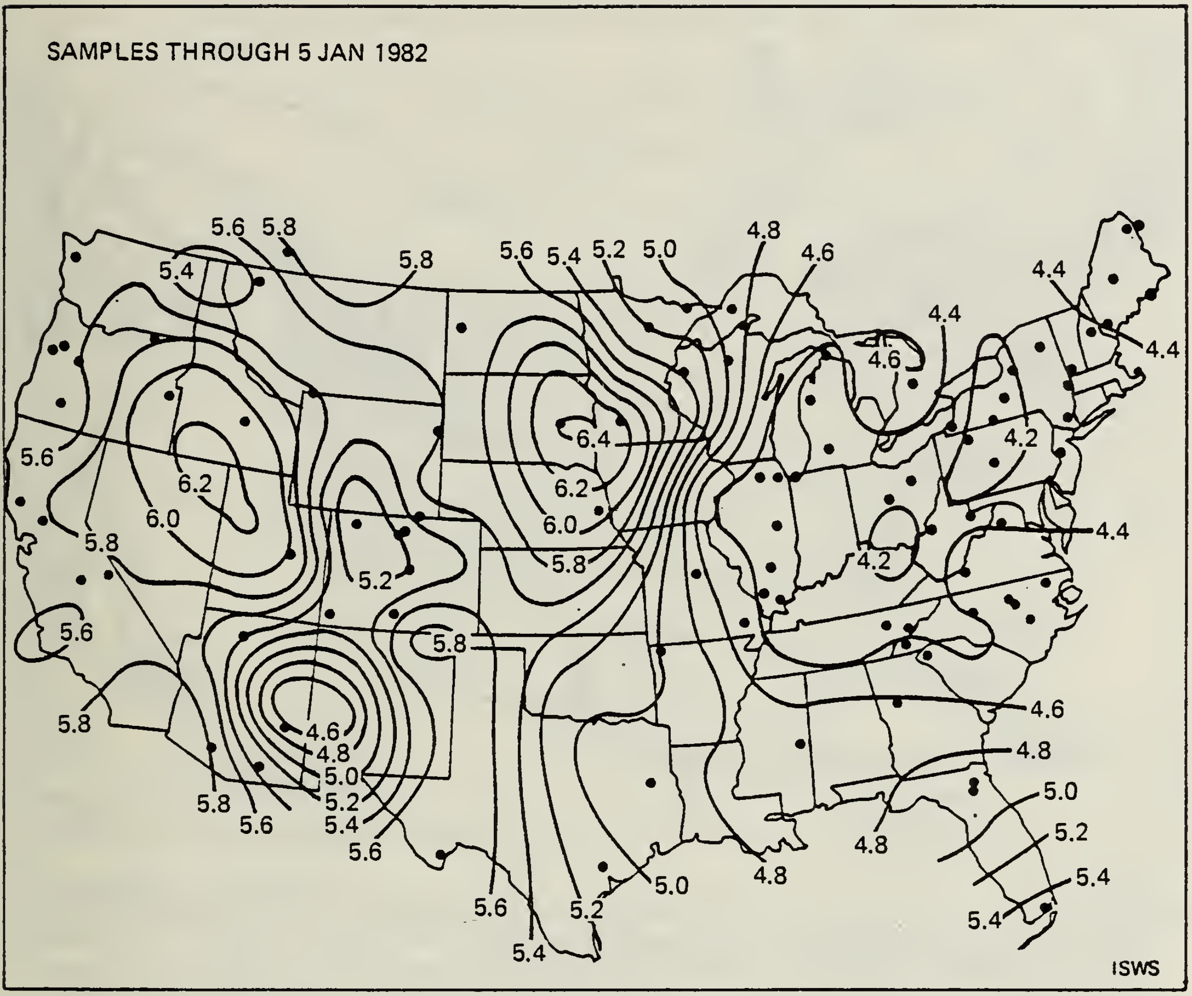

Figure 15. The same as figure 12, but includes samples through January 5, 1982 and additional stations. Note the relative stability of the northeast U.S. pattern and that of the north-central Great Plains (see text).

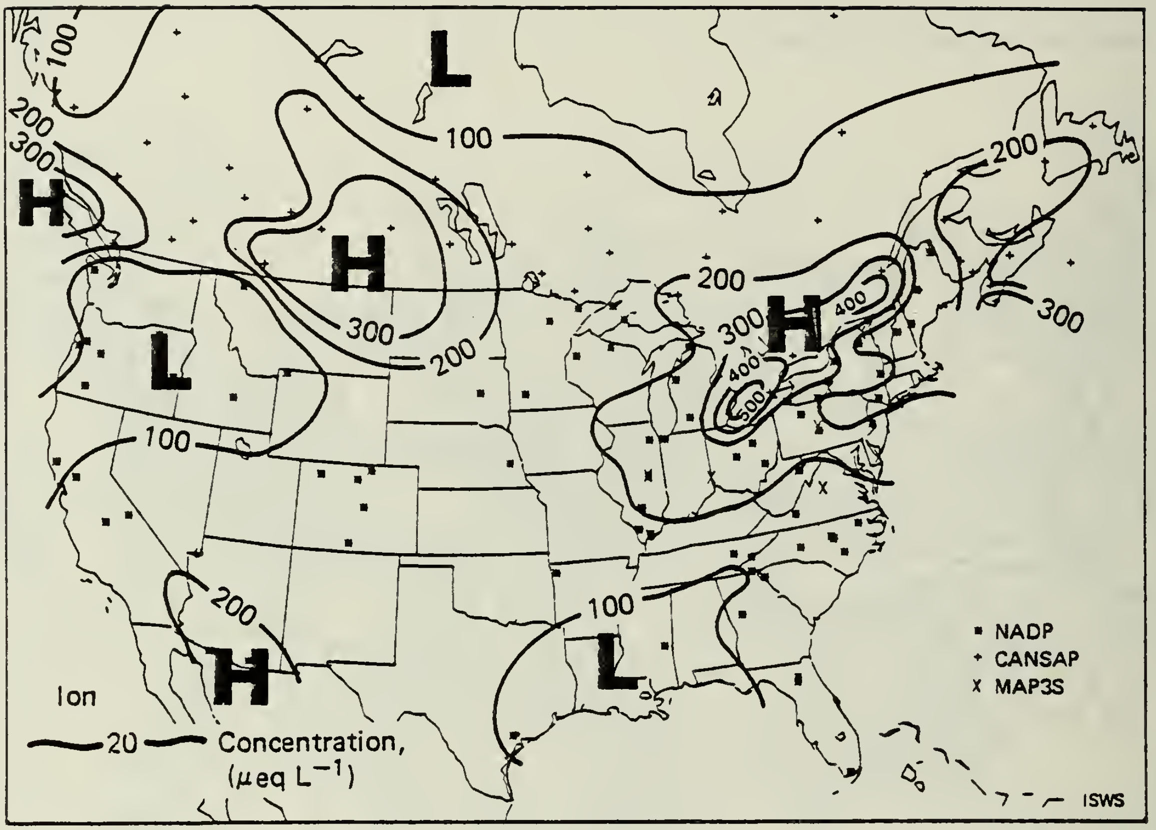

Figure 16. The precipitation-weighted average total ion concentration (μeq L^{-1}) as determined from measurements of H^+, Na^+, Ca^{2+}, NH_4^+, NO_3^-, Cl^-, and SO_4^{2-}. Samples through 1981 were used in this analysis.

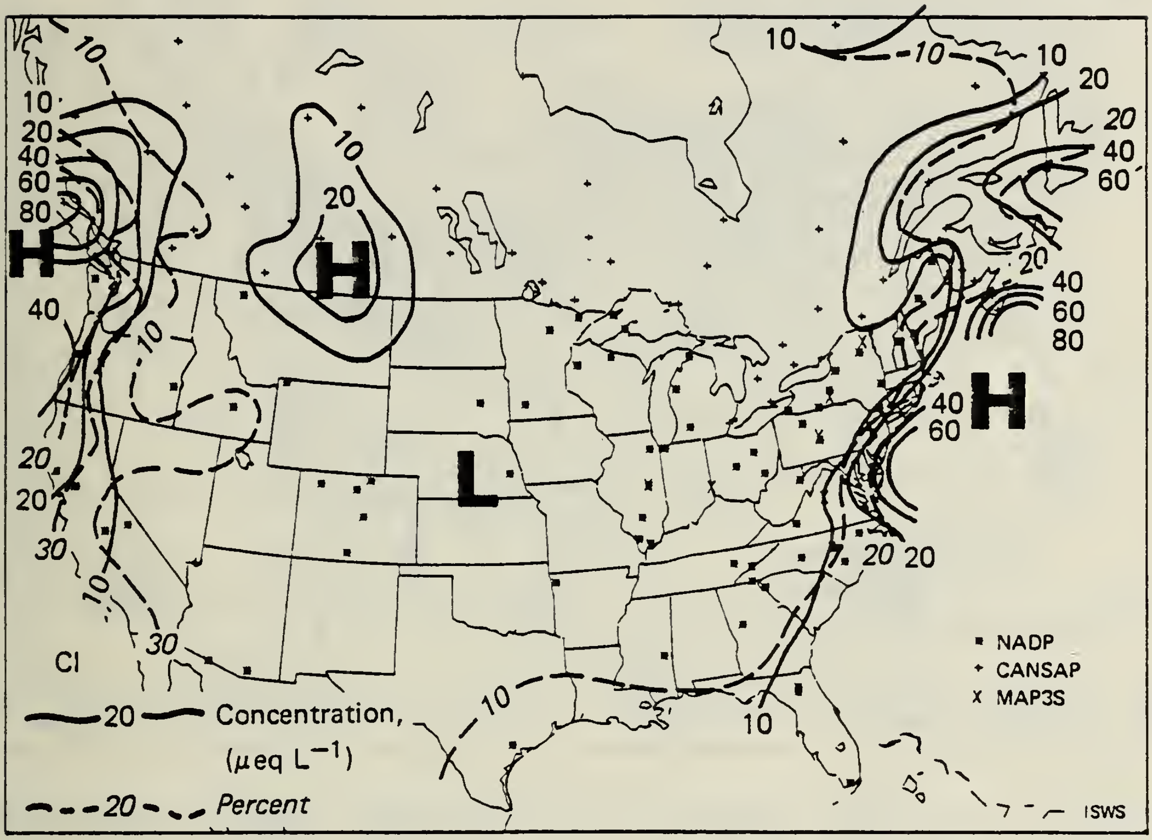

Figure 17. The precipitation-weighted chloride concentration (μeq L^{-1}) for all samples available through 1981. The solid line depicts the concentration and the dashed line the percentage of the total ion concentration shown in figure 16. Note the expected coastline maximums.

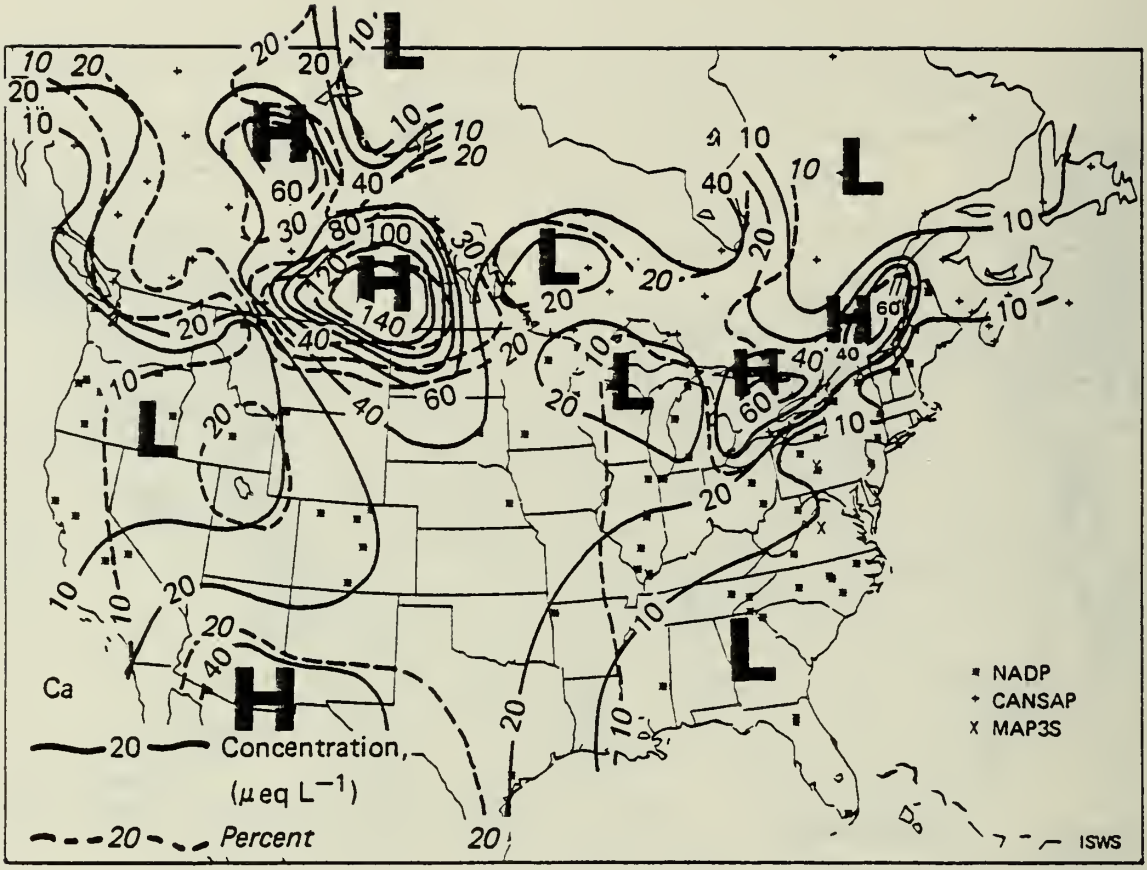

Figure 18. The same as figure 17, but for calcium. This ion associated with crustal dust maximizes in the continental interior.

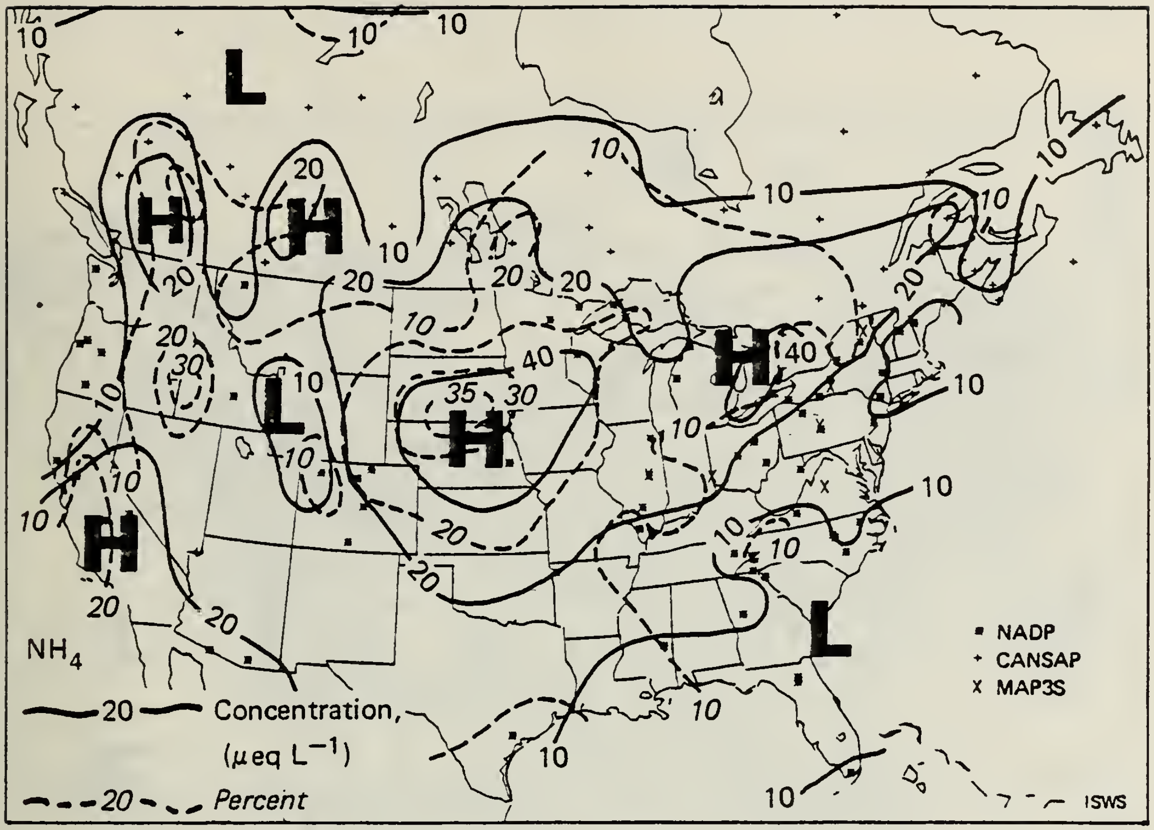

Figure 19. The same as figure 17, but for ammonium. The maximum in the Great Plains may be influenced by the extensive feed-lot industry in that area.

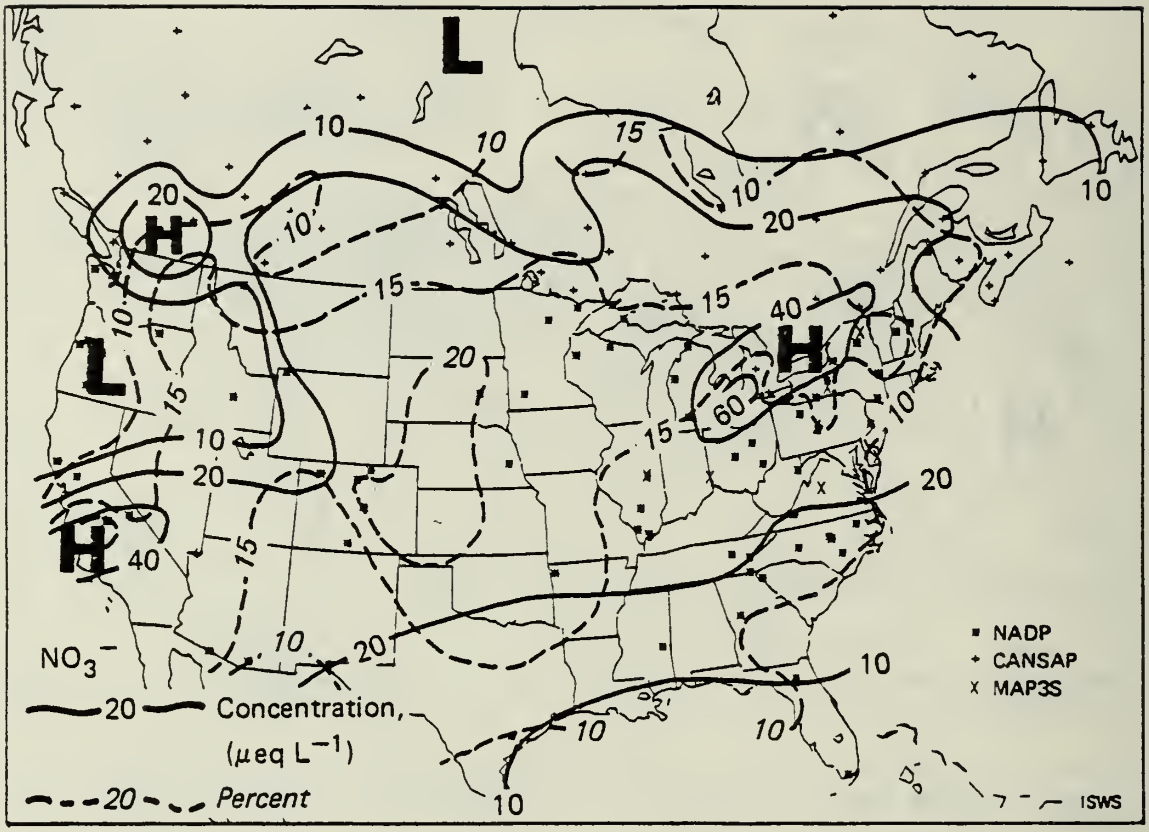

Figure 20. The same as figure 17, but for nitrate. Values in excess of 20 μeq L^{-1} dominate nearly two-thirds of the U.S. and extend between the east and west coasts.

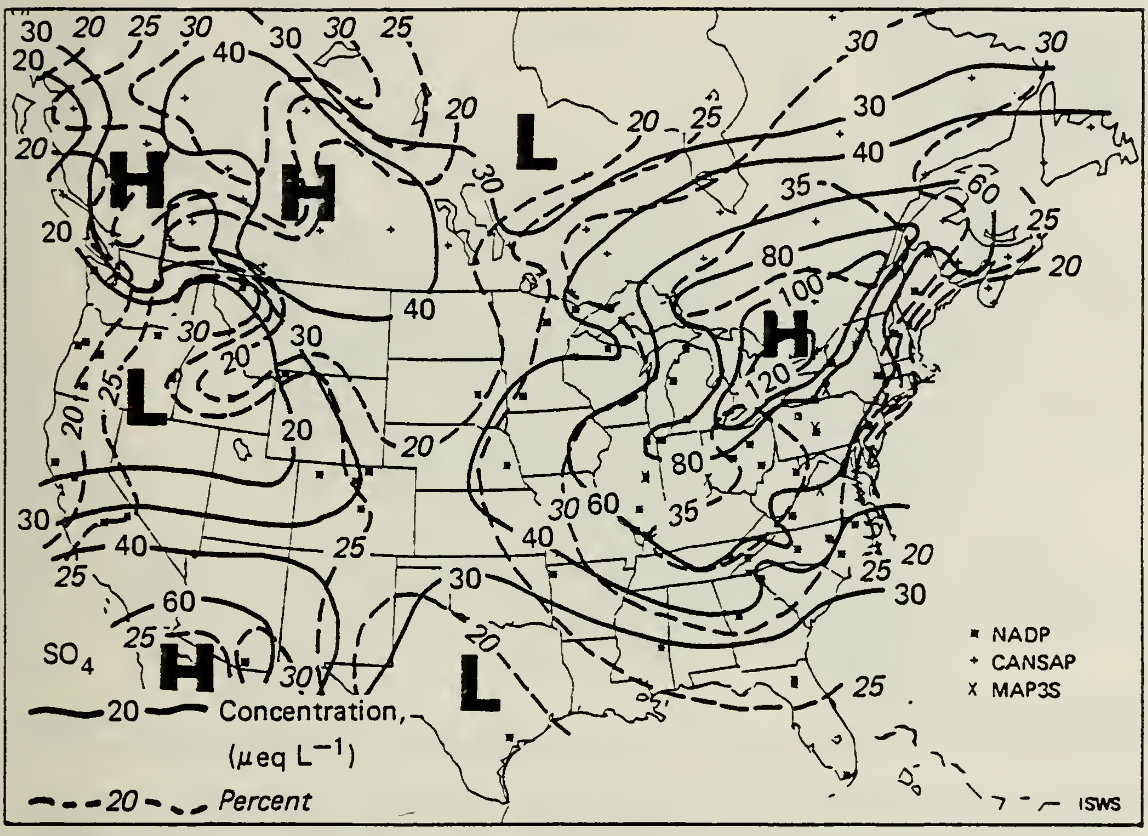

Figure 21. The same as figure 17, but for sulfate. This ion accounts for more than one-third of the total ion concentration in the U.S. from the Mississippi River eastward and from Tennessee and North Carolina northward.

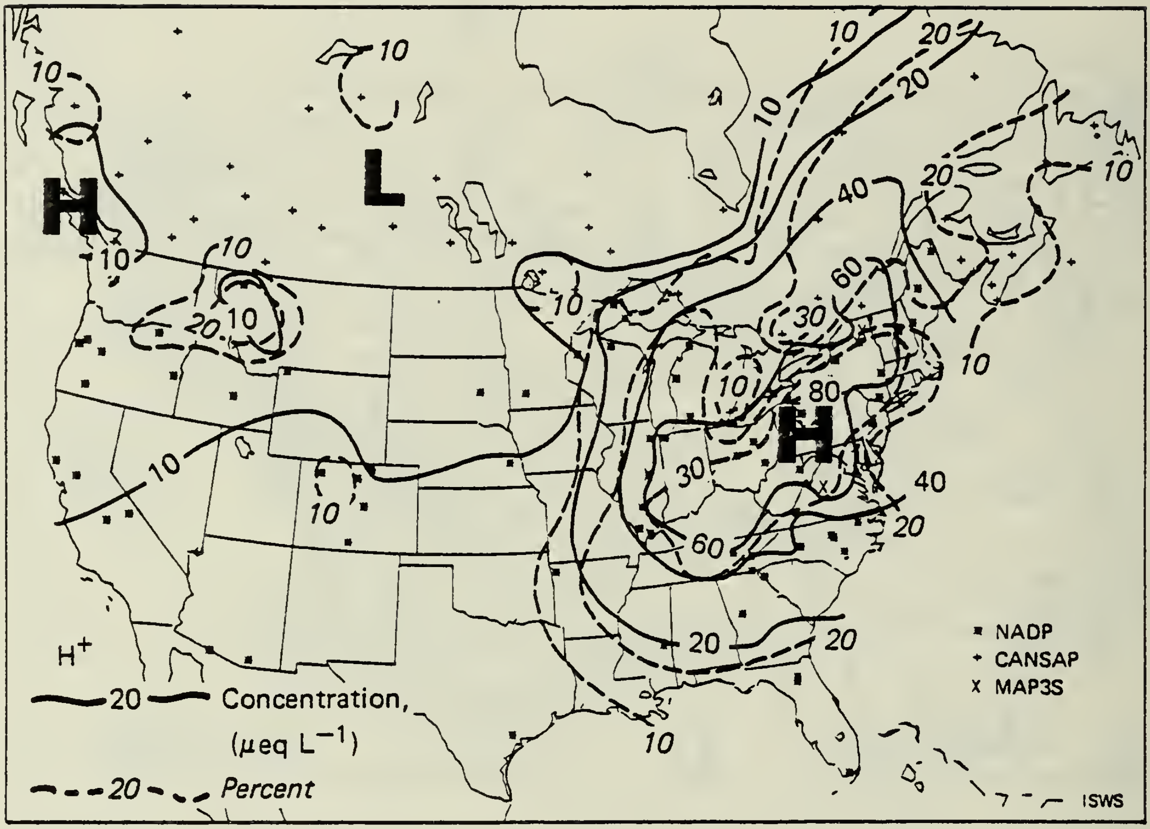

Figure 22. The same as figure 17, but for hydrogen determined from pH determinations. This ion accounts for about one-third of the total ion concentration along the Ohio River Valley northeastward to eastern New York.

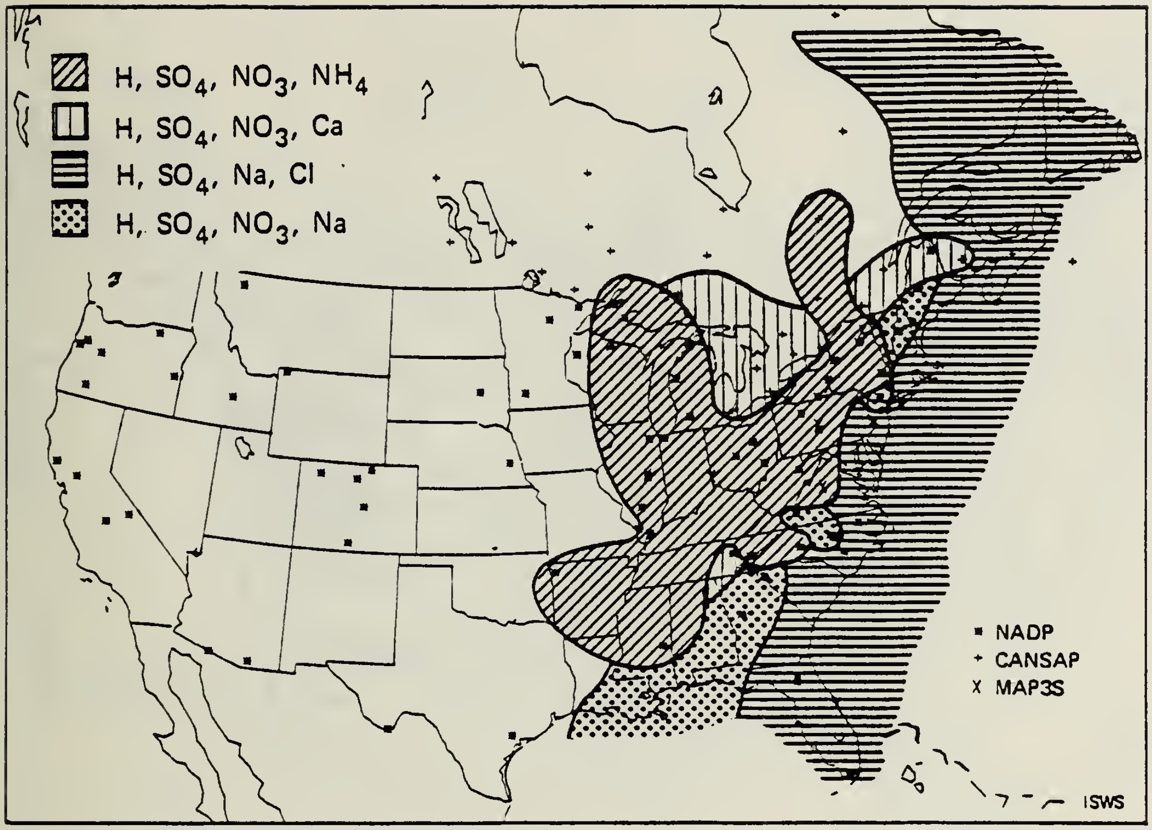

Figure 23. The four ions that contribute $\geq$90% of the total ion concentration in the eastern U.S. Note that H^+, SO_4^{2-}, and NO_3^- dominate except along the east coast. The fourth ion varies regionally. The data through 1981 do not permit a similar analysis of the western U.S.

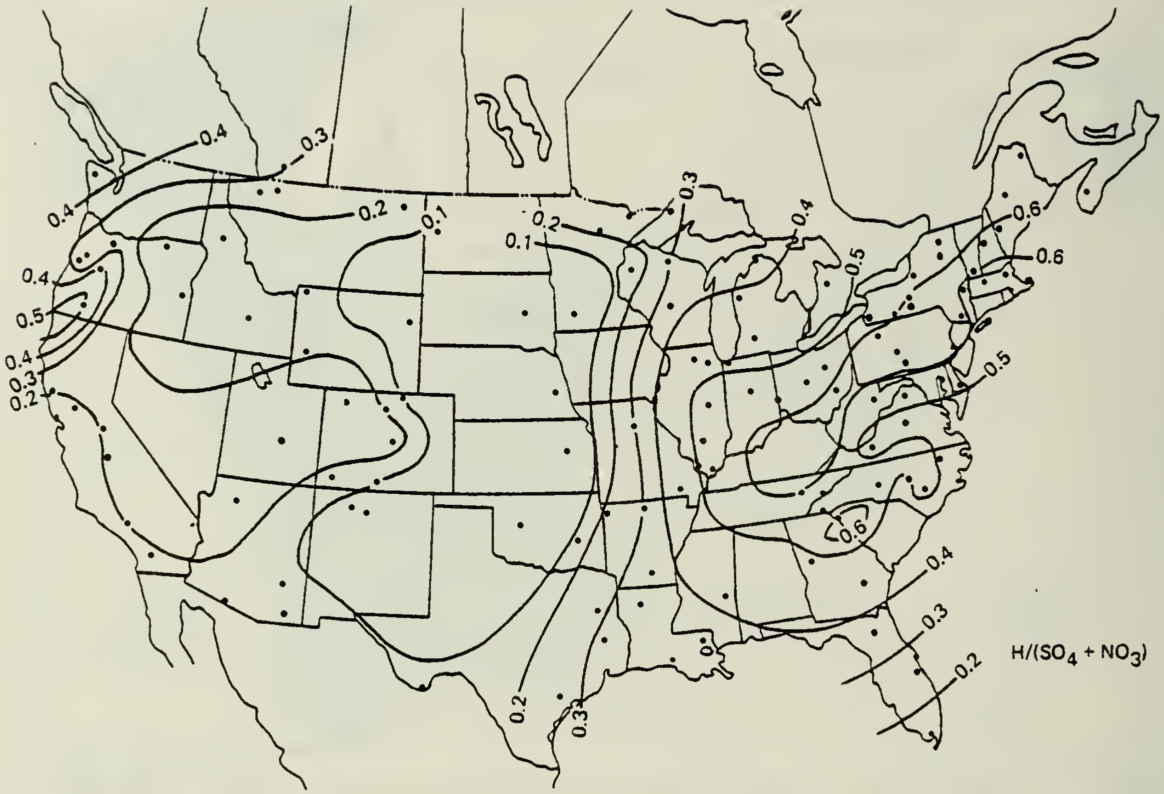

Figure 24. The average ratio of hydrogen to the sum of sulfate and nitrate. A ratio of one would suggest that the hydrogen ion arises from sulfuric and nitric acid in precipitation. Note the maximum value of ≥0.6 extends along the Ohio River Valley northeastward to Maine.

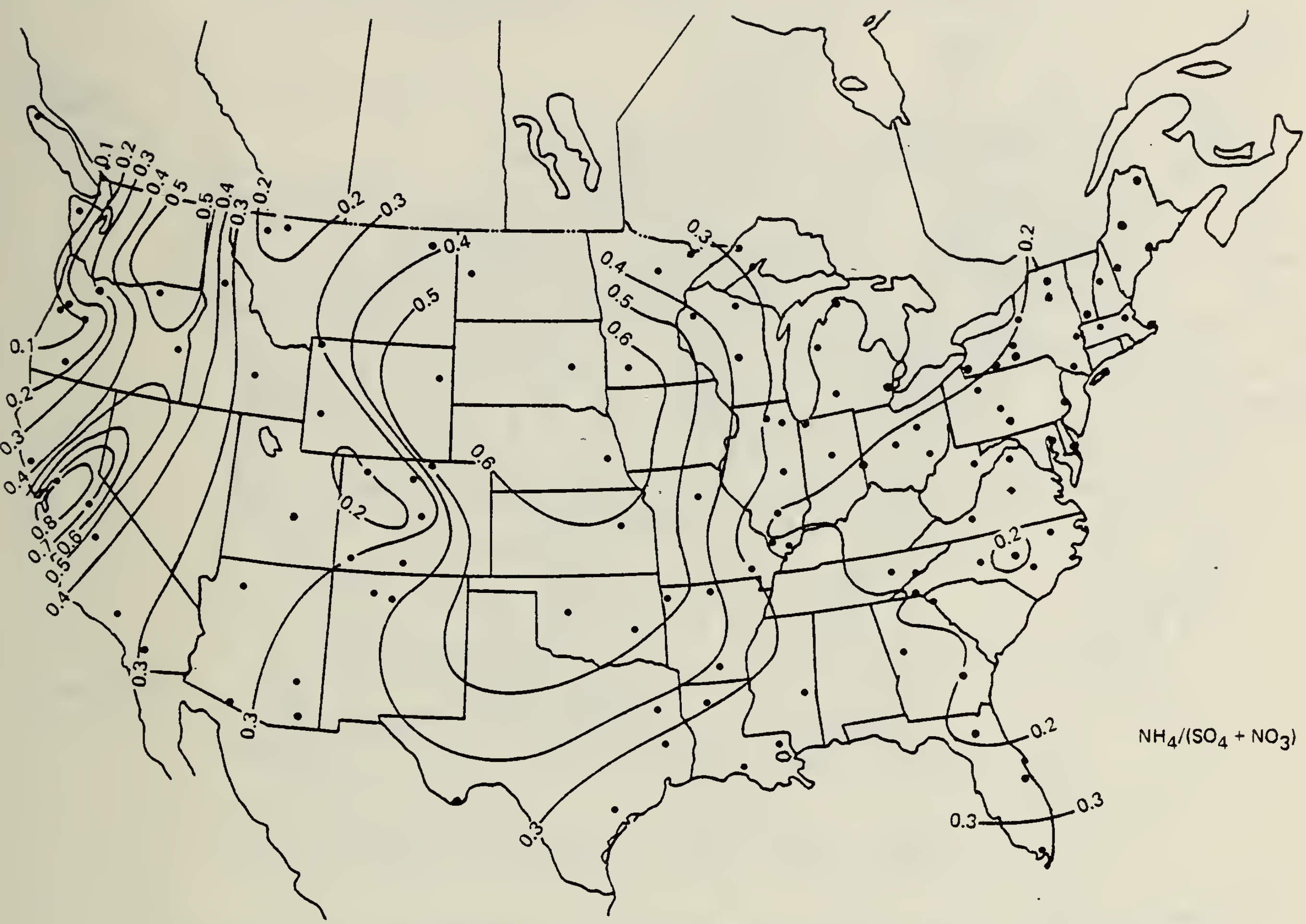

Figure 25. The same as figure 24, but for ammonium to the sum of sulfate and nitrate. The Great Plains maximum of $\geq$0.6 suggests the presence of ammonium sulfate and/or ammonium nitrate.

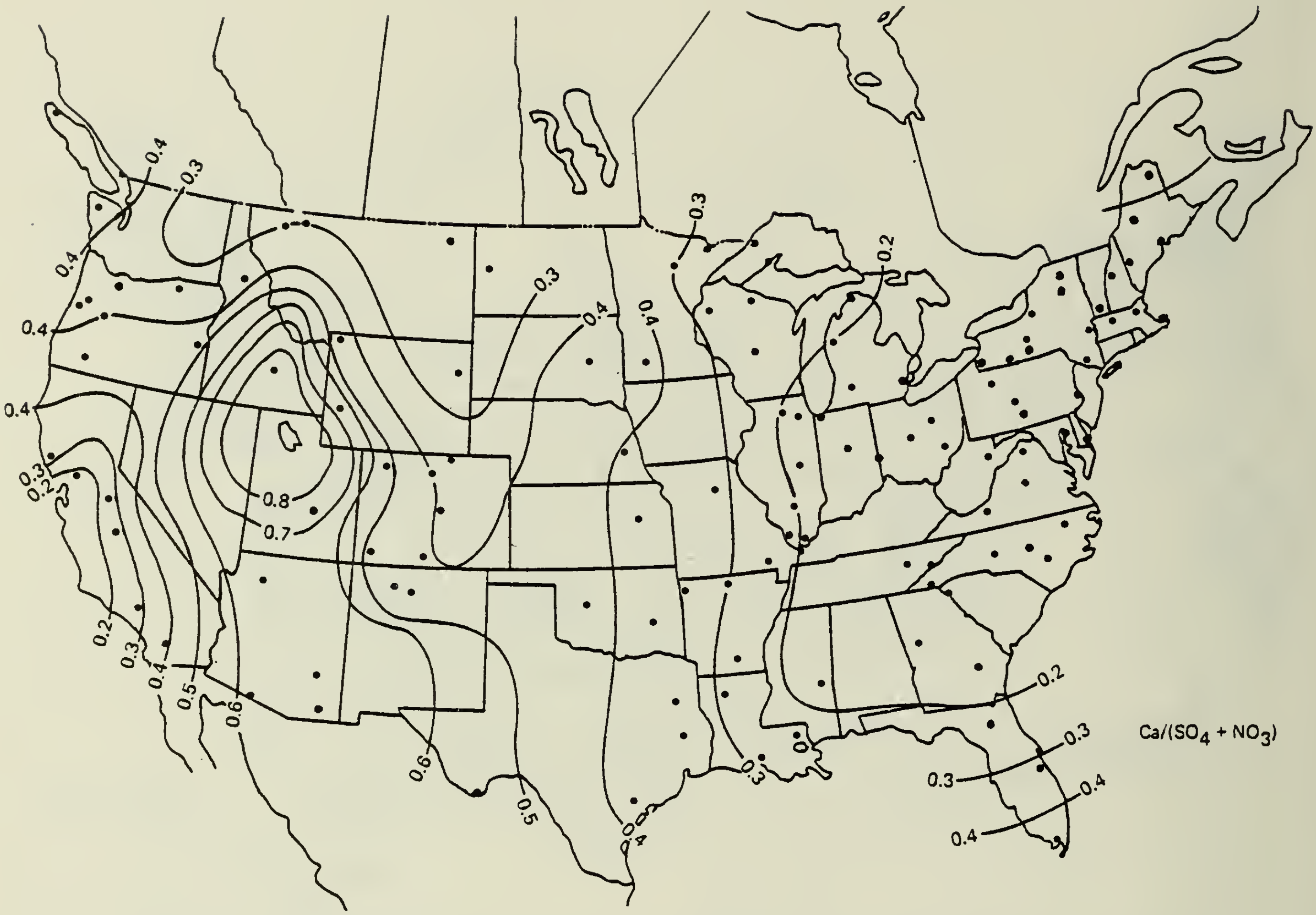

Figure 26. The same as figure 24, but for calcium to the sum of sulfate and nitrate. The Great Basin maximum of ≥0.8 suggests the presence of calcium sulfate and/or calcium nitrate.

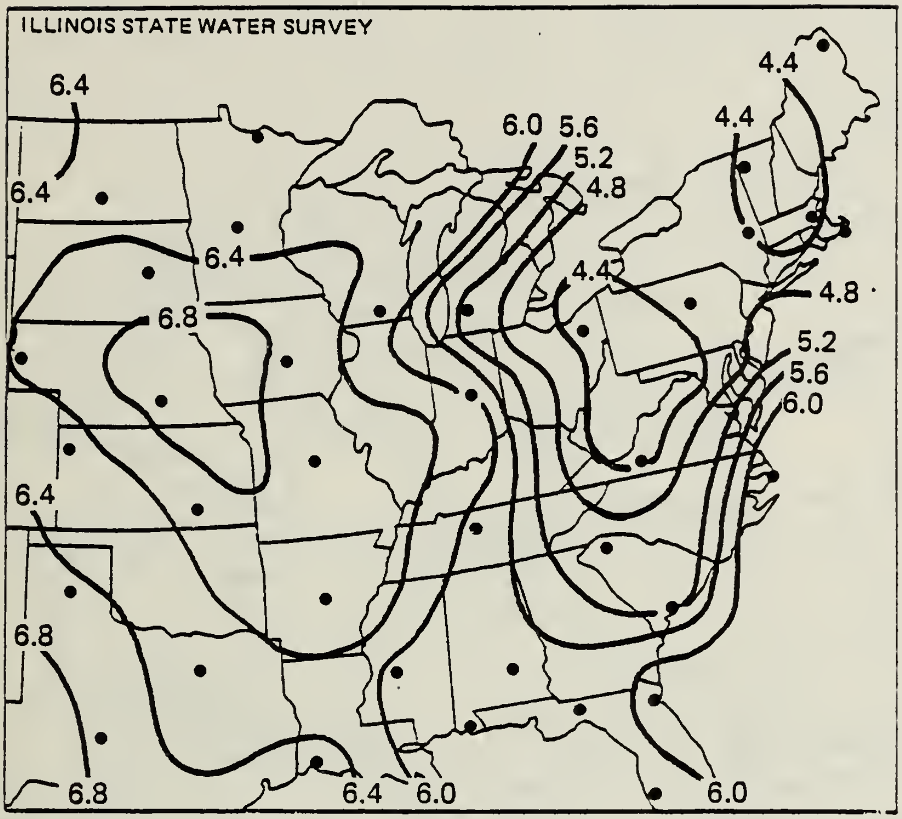

Figure 27. The pH distribution calculated from the analyses of monthly samples collected by Junge during 1955-1956.

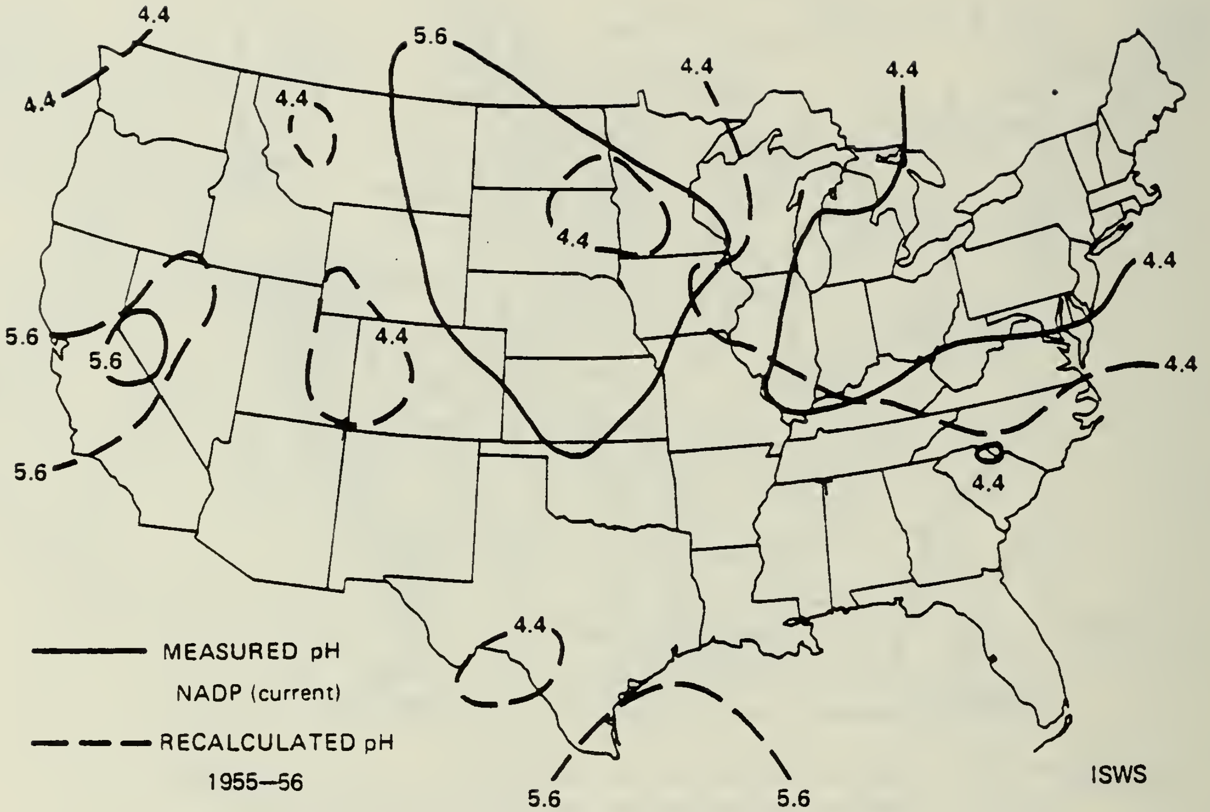

Figure 28. The dashed line represents recalculated values of pH after adjustment for anomously high concentrations of calcium and magnesium. The solid line represents the measured precipitation-weighted pH values from NADP samples through July 1980. The agreement in the northeast U.S. is striking.

ACIDIC DEPOSITION: UNCERTAINTIES IN MODELING TRANSPORT, TRANSFORMATION AND DEPOSITION AND POLICY IMPLICATIONS

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State University of New York at Albany

Regional models have been developed--and have been operated as part of the U.S.-Canadian joint efforts organized under the Memorandum of Intent (1980)--in an attempt to establish source-receptor relationships between acidic deposition precursors and wet and dry deposition. Two distinct types of models are in use today for studying long-range transport of air pollutants: Eulerian grid models and Lagrangian trajectory models. Existing acid deposition models have already contributed to our understanding of the annual wet deposition over a large geographic area such as the eastern United States. But similar efforts for shorter time periods are not thought to be feasible at this time. Similarly, efforts to model dry deposition are hampered by the almost complete lack of field measurements against which to judge the model results. Obviously, uncertainties in our knowledge of transport and chemical transformations are two of the basic reasons for the limited faith that the community at large has in current acid deposition models.

Meteorologists have approached the transport problem in a number of ways. The simplest method is to use observed values of horizontal winds at specified altitudes to calculate by interpolation where the winds would carry a given air parcel containing the material of interest. This constant-level or isobaric trajectory model (Heffter and Ferber, 1977) ignores the vertical component of the wind, so the method does not provide true trajectories in many circumstances such as near frontal zones or over mountain ranges. On the basis of thermodynamic arguments, it is expected that vertical motions of air parcels should adhere rather closely to constant-entropy surfaces in the atmosphere, and from this isentropic trajectory models have evolved. However, the isentropic model still does not account for vertical motions in clouds or when isentropic surfaces intersect the terrain. Although curved-trajectory simulations can produce rather reliable results in simple meteorological situations, they are frought with uncertainty when conditions become complex, such as near frontal systems. For example, compared with the interior of the United States, a much larger portion of the average annual precipitation in the Northeast is associated with cyclonic disturbances. Thus the areas of eastern North America regarded as being sensitive to acid deposition receive precipitation from storm systems that are difficult to "model" and with origins at almost any latitude in the interior or the West. In other words, it is precisely in storm environments that it is most critical to trace pollutants with accuracy and in those situations, current models are weakest.

Verification of any transport model is critical to its acceptance both as a descripton of scientific understanding and as a tool for analyzing policy choices. Methods include constant altitude balloons (Pack et al., 1978) and chemical tracers. The first method did not yield in the past conclusive answers over longer transport distances and the latter method has only very

recently been successfully employed in the field of long-range transport (Captex, 1983). While techniques for computing trajectories have advanced markedly over the past decade, they still are plagued by a host of additional uncertainties: most notable are the sparsity of meteorological data, both in time (upper-air soundings are made only twice daily) and space (stations are widely separated in the U.S.).

A "credible" model* should consider as a minimum the following transport and mixing parameters:

HORIZONTAL MOTIONS

° Diffusion
° Windshear
  - nocturnal jets
  - frontal systems
° Orographic effects
° Mixing layer depth
° Above boundary layer

VERTICAL MOTIONS

° Buoyant bubbles
° Cloud venting
  - updrafts and downdrafts
  - injection into free troposphere or stratosphere
° Orographic effects

It is not possible at this time to unequivocally associate an uncertainty value to current acid deposition models resulting from their simplified treatment of transport processes. It is understandable, however, why a healthy degree of skepticism should be applied regarding the usefulness of these current models in predicting acid depositions in general but in particular on an event-by-event basis.

The deterministic models that are available by necessity employ approximations to the atmospheric transformation processes that are hypothesized to be important to acid deposition. Generally, the chemical tranformations are treated parametrically, reflecting a lack of knowledge of specific mechanisms. For example, the models selected by the U.S./Canada Work Group #2 employ the following approximation for the combined gas phase-aqueous phase chemical transformations:

---

* Models that are built on basic physical and chemical processes and that can test hypotheses and guide the design and assessment of field measurement programs with the eventual goal of predicting acid deposition rates and source-receptor relationships and of providing reliable estimates of the effects of emission control strategies (NCAR: Regional Acid Deposition: Design and Management Plan for a Comprehensive Modeling System. 1983)

Model Type	Oxidation Rate for SO_2 in %/hr	Wet Removal Rate %/hr	Type
AES	Constant: 1	Proportional to daily precipitation rate and inversely to mixing height	Lagrangian-box
ASTRAP	Diurnal and seasonal varying: summer: 1.1 winter: 0.55	Bulk S: minimum value or dependent on six-hour precipitation rate	Statistical-trajectory
CAPITA	Constant seasonal varying: winter: 0.83 spring/fall: 1.20 summer: 1.53	Proportional to probability of precipitation in each six-hour period	Monte Carlo
ENAMAP-1	Constant: 1.0	Proportional to three-hour precipitation rate	Puff-trajectory
MEP	Constant: 1.0	SO_2: dependent on pH and temperature SO_4^{2-}: dependent on precipitation rate	Lagrangian
MOE	Constant: 1.0	SO_2: 10.8 SO_4^{2-}: 36.0	Statistical
RCDM	Constant: 1.0	Bulk S: proportional to precipitation rate and average duration of dry and wet periods	Analytical
UMACID	Diurnally varying daytime rate varies as sine wave with midday peak at 4.0 nighttime rate: 0.5	SO_2: proportional to hourly precipitation rate and inversely proportional to mixing height SO_4^{2-}: dependent on hourly precipitation rate and inversely proportional to mixing height	Puff-trajectory
SURADS	Constant: (0.5-3.0) or diurnally varying as calculated	Not yet included	Eulerian

Model Type	Oxidation Rate for SO_2 in %/hr	Wet Removal Rate %/hr	Type
ELSTAR	Variable-tied to photochemical model	Not yet included	Lagrangian trajectory
RTM-II	A function of solar zenith angle and geographic location Northeastern U.S.: 0.78 average for summer	SO_2: rainfall rate and precipitation pH dependent SO_4^{2-}: rainfall rate and rain-cloud dependent	Hybrid Lagrangian/ Eulerian

It becomes apparent that none of the currently available models contains an aqueous phase submodule capable of realistically treating the SO_2 transformations. Furthermore, at this time none of the models contains any detailed nitrogen chemistry.

Considerable insight has been obtained over the past years into the chemical transformations that occur during transport. For example it is now known that cloud and precipitation elements play a major role in the overall conversion of sulfur and nitrogen compounds to sulfates and nitrates: rates of oxidation of SO_2 through gas phase reactions are relatively slow (a few percent per hour during daylight), whereas in theory those for the aqueous phase pathways may be as high as 100 percent/hour for seemingly realistic concentrations of the reactants in cloud water. A comparison of reaction pathways for aqueous phase oxidation of SO_2 is shown in Figure 1 (Martin, 1983). The trend of rising conversion rates with increased pH results from either the rising equilibrium concentration of sulfur (IV) or the sensitivity of the rate constants to pH, or both. H_2O_2, which undergoes an acid-catalyzed reaction, is the only oxidant for which the rate dependence on $[H^+]$ compensates for the decreased solubility of SO_2 with increased $[H^+]$. The concentrations of reactants used in deriving Figure 1 are representative of those that might be anticipated in the atmosphere. Oxidation by H_2O_2 dominates all reactions for conditions of low pH. Oxidation rates can be greater than 100 percent/hour.

The rate for oxidation by ozone varies from about 10 percent/hour at pH of 4.5 to about 1 percent/hour at pH of 4. The contributions from the Fe^{3+}, Mn^{2+}, and carbon catalyzed reactions are below 1 percent/hour for solutions of pH < 4.5 but could be significantly higher in highly polluted regions. Oxidations by NO_2 and HONO is less significant under the conditions listed in Figure 1. An additional influence on the rates and kinetics of sulfate oxidation in clouds and precipitation can arise from the complexation of HSO_3^- (aq) by aldehydes scavenged by cloud droplets. The result of such interactions could increase the solubility of SO_2 in the droplet and conceivably retard sulfite oxidation by the oxidants. Although there is significant theoretical evidence that H_2O_2 may be the most important oxidizing agent for acid generation in the aqueous phase, unambiguous experimental measurements of H_2O_2 levels in air and even in cloud water have not been possible to date. The possible roles for peroxyacetylnitrate, peroxynitric acid, CH_3O_2H and other peroxides in aqueous phase sulfite oxidation remain to be evaluated.

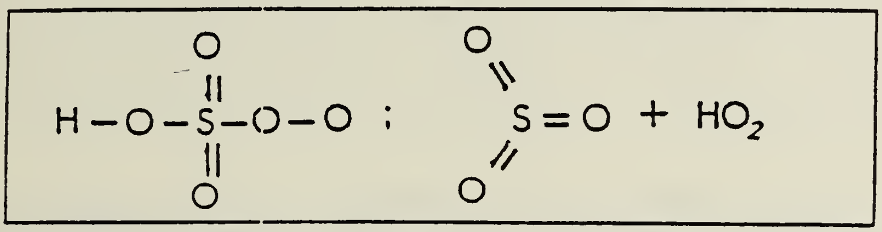
There is some evidence of the formation of HNO_3 in clouds and precipitation water. Both theory and experiments suggest that HNO_3 may be formed rapidly from a combined gas phase-aqueous phase process via N_2O_5 generated by O_3-NO_2 reactions (Gertler, et al., 1982). Although significant uncertainty remains concerning the source of HNO_3 in clouds and precipitation water, the limited evidence currently available favors the probable importance of the formation of N_2O_5 followed by its reaction in cloud droplets to form HNO_3.

This does not mean, however, that aqueous phase reactions dominate the overall production of sulfates. According to current understanding, the SO_2 gas phase conversion rate characteristic of polluted summer sunny skies is of the order of 16 percent per 24-hour period and 3 percent per 24-hour period during winter sunny weather. These rates are sufficiently large to compete with the aqueous phase processes when averaged over longer periods of time: The relative importance of either mechanism varies, of course, depending on a variety of meteorological conditions such as the extent of cloud cover, relative humidity, presence and concentrations of various pollutants, intensity of solar radiation, and amount of precipitation.

Most researchers who have analyzed regional air-quality data have assumed a linear mechansim for transforming SO_2 into sulfate (gas phase reaction). In recent years this assumption was seriously challenged, based primarily on the work of Rodhe et al., 1981. "Nonlinear" transformation would prevail if the production of H_2SO_4 from SO_2 consumes OH. Near linear chemistry, on the other hand, would not result in a termination of the OH and HO_2 chains.

The chemical sequence can be summarized as follows:

> The SO_2 species may react with the OH to form the intermediate $HOSO_2$ radical. The fate of the $HOSO_2$ radical is believed to be reaction with O_2 to form a peroxy radical or, alternatively, SO_3 and HO_2, i.e.:



> The peroxy species may react with NO or HO_2 or perhaps hydrate as a result of collisions with H_2O. The only certainty in this chemistry now appears to be that like SO_3 the final product is some form of sulfuric acid. The latter species is rapidly removed from the gas phase by various heterogeneous processes.

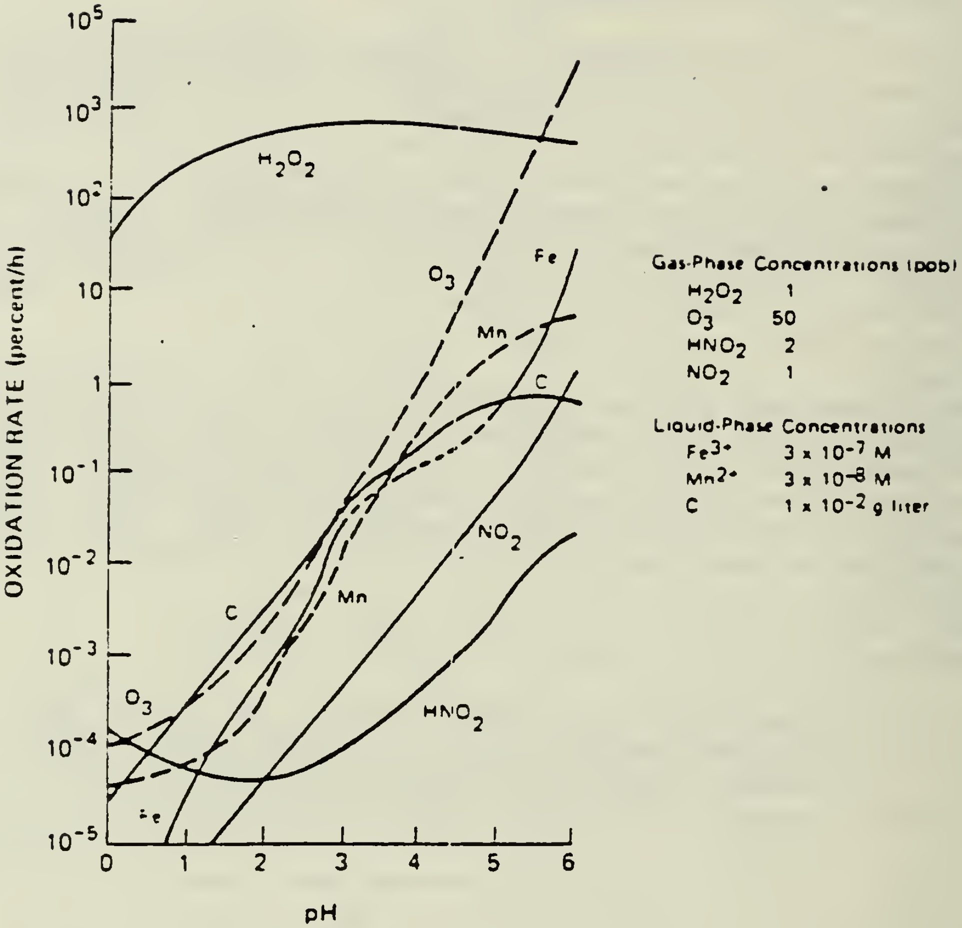


Figure 1. Theoretical rates of liquid phase oxidation of SO_2 assuming 5 ppb of SO_2, 1 ml/m^3 of water in air, and concentrations of impurities as shown.
Source: Martin (1983)

NET CONSUMPTION OF OH:
("NONLINEAR TRANSFORMATION")

$$HOSO_2 + O_2 \rightarrow HOSO_2O_2$$

$$HOSO_2O_2 + NO \rightarrow HOSO_2O + NO_2$$

$$HOSO_2O + HONO \rightarrow H_2SO_4 + NO_2$$

NO TERMINATION OF HO – HO2 CHAINS:

$$HOSO_2 + O_2 \rightarrow HO_2 + SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Recent laboratory results strongly suggest that the SO_2 gas phase conversion indeed is linear, i.e., does not consume OH radicals. This finding restores some of the severe doubts that were expressed against all current models containing "linear" transformation chemistry. Of course there still exists the possibility that the aqueous phase conversion of SO_2 may be oxidant limited (H_2O_2 limited). Indeed, results from the ASRC field station station at Whiteface Mountain strongly suggest that possibility: during the winter months, the H_2O_2 levels in clouds were very low, sometimes below 1 ppb (cloud water) rising to over 1,000 ppb in the summer period. Well over 65 percent of the annual sulfate in precipitation is deposited during the summer months which might therefore mask the obvious oxidant limitation that prevails during the winter months. Hence, on an annual basis the aqueous phase oxidation might be closer to linearity. As a result, the chemistry of gas and aqueous phase sulfur might be "not significantly nonlinear" as was recently assessed by the National Academy report on "Acid Deposition" (1983).

There are currently no efforts reported in the reviewed literature focussing on analyzing the sensitivity of model predictions to uncertainties in chemical initialization and parameterization. There is also no information available in the reviewed literature on the range of uncertainty in general of current models. The ASTRAP-model performance was recently tested by Shannon (private communication, September 1983) against the 1980 annual wet sulfate and nitrate deposition in the eastern U.S. His model could explain 70 to 75 percent of the variance with a correlation coefficient of 0.85. Because of the lack of appropriate field data no such test can be performed for dry deposition. Similar future efforts involving all current models will determine if indeed current models can reasonably well reproduce the long-term field

results. Some purists mandate that an uncertainty analysis should include performance verification, estimation of component errors and testing of sensitivity. For that purpose the Fourier Amplitude Sensitivity Test (FAST) has been suggested which is well suited for situations where many model parameters are varied over large ranges simultaneously (McRae et al., 1980; Koda et al., 1979; Cukier et al., 1978).

Whatever the appropriate procedure for model testing, etc., may be, the fact remains that this is a task that still needs to be completed by all current "model builders." It is therefore not surprising when the NAS report on acid deposition expressed reservation and conservatively stated: "We do not believe it is practical at this time to rely upon currently available models to distinguish among alternative strategies."

However, decisions on almost all issues of public concern are routinely made in light of uncertainties in knowledge. What, then, are the policy implications? It appears to be prudent to adopt a policy or policies for control strategies that are inherently flexible and can adapt to the changing base of scientific understanding. What is called for in a situation like this is an experiment that satisfies several goals:

- reduce sulfur deposition in the most sensitive regions of eastern North America where "acid rain" damage has been clearly demonstrated;

- significantly improve our knowledge on source-receptor relationships through carefully designed experiments and monitoring activities;

- minimize the economic burden resulting from sulfur emission reduction while maximizing the anticipated reduction in sulfur deposition within the "targeted" area(s).

The above strategy would recognize that it is probably unrealistic at this time to seek a significant and regionally equal reduction throughout the 31 states east of the Mississippi in order to guarantee an equal reduction in sulfur deposition in those areas sensitive to and already impacted by "acid rain." The remaining problem then is to decide on the appropriate sensitive "target area" and select the "zone of potential influence" for this selected area.

From a practical point of view there appears to be little doubt that the Adirondack Mountains and the northeastern U.S. in general have suffered the most from the deposition of acidifying substances. Figure 2 shows the annual precipitation-weighted sulfate concentration ranging from 2.1 to 2.6 mg/liter for 1980. The annual amount of precipitation in this region is of the order of 110 cm which then yields average deposition values between 23 and 28 kg/ha.yr. Deposition values below 20 kg/ha.yr are desirable in order to avoid environmental degradation which would mandate an average deposition reduction in this region of the order of 25 percent below current levels. The states surrounding the Adirondacks, i.e., at a minimum Pennsylvania, West Virginia, Ohio, Ontario, Quebec, and of course New York itself, would have to "participate" in the experiment and reduce their emission levels by a large enough amount to cause a "measurable" effect on the Adirondacks and regions

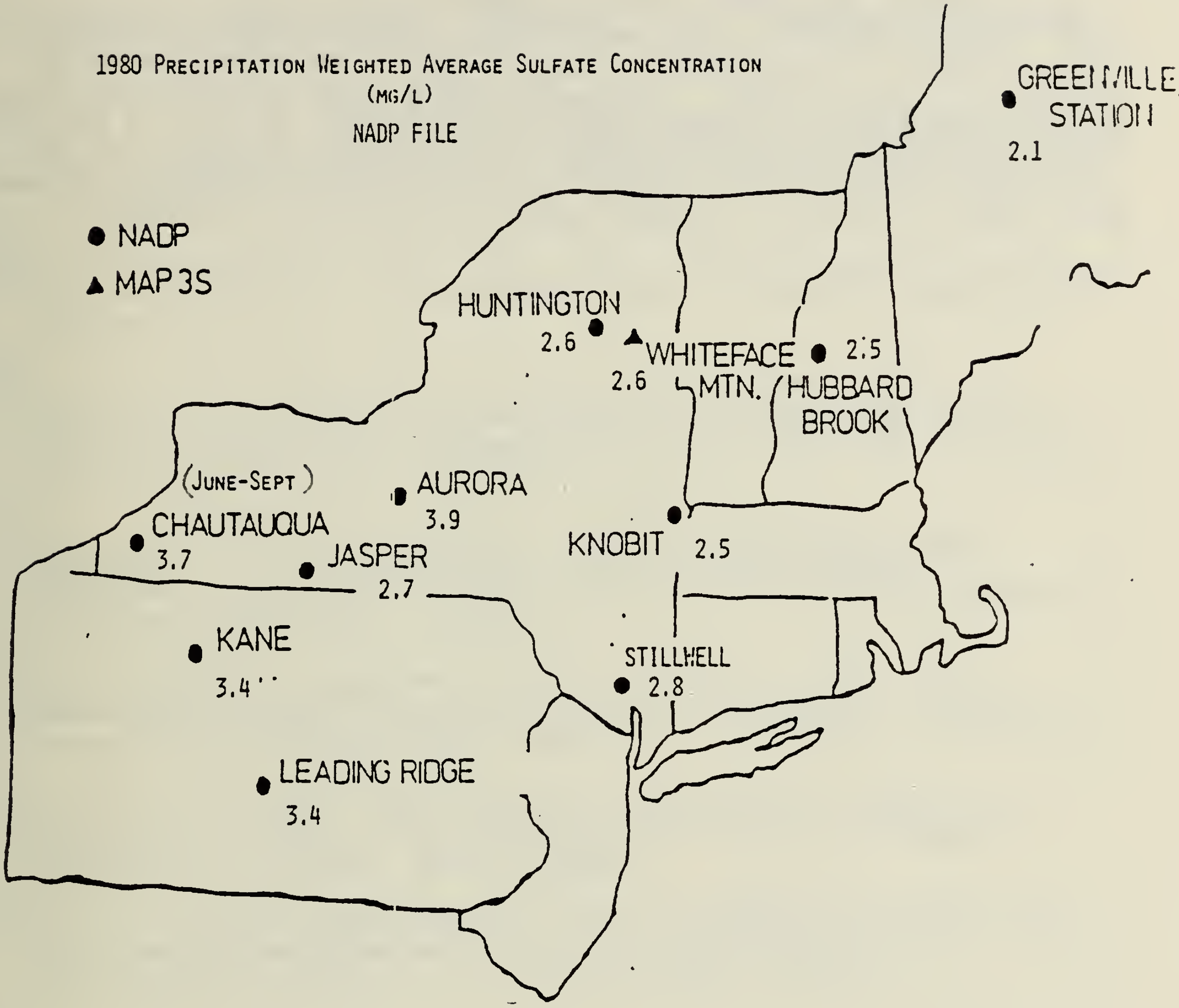


Figure 2

Source: J.W. Wilson, personal communication.

to the northeast. Because of our limited knowledge on source-receptor relationships it is not possible to quantify "large enough emission reductions." As in any experiment, one has to take a certain risk. Therefore, as a working hypothesis, one might call for an area-wide overall reduction of sulfur emissions from the above participating states of about 25 percent and hope for a resulting deposition reduction of at least 20 percent, which can be detected by a sophisticated wet deposition network.

An experiment as described above and targeted towards a sensitive region would avoid the doubtful task of establishing with some degree of certainty a source-receptor relationship before any emission reduction program can be initiated. Such a policy, if implemented, would allow research to catch up with the desire of policy makers and the general public at large to efficiently and swiftly reduce the deposition of acidifying substances in all ecologically sensitive regions to below 2 kg of sulfate per hectare and year while keeping the overall economic impact of such steps at a minimum.

REFERENCES

Cukier, R.I., H.B. Levine and K.E. Shuler, 1978. Nonlinear sensitivity analysis of multiparameter model systems. Journal of Computational Physics, 26: 1-42.

Gertler, A.W., D.F. Miller, D. Lamb and U. Katz, 1982. SO_2 and NO_2 reactions in cloud droplets. Abstracts, A.C.S., 185th National Meeting, Las Vegas, Nevada, pp. 112-115.

Heffter, J.L. and G.L. Ferber, 1977. Development and verification of the ARL regional-continental transport and dispersion model. Proceedings of the Joint Conference on Application of Air Pollution Meterology, Boston, MA, American Meteorological Society, pp. 400-407.

Koda, M., G.J. McRae and J.H. Seinfeld, 1979. Automatic sensitivity analysis of kinetic mechanisms. International Journal of Chemical Kinetics, 11: 427-444.

McRae, G.J., J.W. Tilden and J.H. Seinfeld, 1980. Global Sensitivity Analysis--A Computational Implementation of the Fourier Amplitude Sensitivity Test (FAST). Environmental Quality Laboratory. California Institute of Technology, Pasadena, CA.

Martin, L.R., 1983. Kinetic studies of sulfite oxidation in aqueous solutions. IN Acid Precipitation: SO_2, NO and NO_2 Oxidation Mechanisms. Atmospheric Considerations. Ann Arbor, Michigan, Ann Arbor Scientific Publications. In Press.

National Academy of Sciences/National Research Council, 1983. Acid Deposition, Atmospheric Processes in Eastern North America. National Academy Press, Washington, D.C., 1983.

Pack, D.H., G.F. Ferber, J.L. Heffter, K. Telegardad, J.K. Angell, W.H. Hoecker and L. Machta, 1978. Meteorology of long range transport. Atmospheric Environment, 12(1-3):25-444.

Rodhe, H., P. Crutzen and A. Vanderpol, 1981. Formation of sulfuric and nitric acid in the atmosphere during long range transport. Tellus, 33(2): 132-141.

BIOLOGICAL CONSEQUENCES OF ACID DEPOSITION

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INTRODUCTION

Preceding speakers have discussed the nature of acid deposition, its causes, the means of its transport and the patterns of its deposition. I will focus on the biological and environmental effects of acid deposition.

In the following discussion I will define acid deposition to include all those substances which intrinsically, or upon reaction, yield a free hydrogen ion. The most important of these substances are sulfuric, nitric, hydrochloric acids, and ammonium ion. I will include wet deposition (precipitation via hydrometeors such as rain and snow) and dry deposition (deposition via particles or gases).

My procedure will be to describe potential effects of acid deposition as they have been either hypothesized or observed somewhere in the world. After these descriptions, I will express my opinion on the seriousness of such phenomena in the Illinois environment.

Information on this topic is enormous, diffuse and contradictory. Fortunately, integrative reviews have emerged with a frequency of about one per year. I will be referring to the most recent of these throughout this presentation. It is a two-volume assessment report compiled by numerous experts from many disciplines and institutional origins. This report was developed and organized by the EPA and released for public review on 20 June 1982.[1] I think it is an objective and thorough review of high credibility. I will simply refer to it as "the EPA report" in the following presentation.

TERRESTRIAL SYSTEMS

Biological impacts of acid deposition are conveniently and effectively divided into those occurring in terrestrial and aquatic ecosystems. Because reactions on land affect aquatic systems downstream, I will begin with a discussion of terrestrial ecosystems.

Whether acidity is deposited by wet or dry means, it is delivered to the canopy first, where chemical interactions occur. With precipitation, the products of these reactions are carried downward by water flux into and through the soil, where further reactions may take place. Finally, if there is

[1] EPA-600/8-83-016A, 016B, May 1983. The acidic deposition phenomenon and its effects. Critical assessment review papers. Vol. 1. Atmospheric Sciences, Vol. II. Effects Sciences.

sufficient water available, soil water moves into groundwater and/or surface springs, streams, ponds, etc. In a sense, the passage of chemicals downward through terrestrial ecosystems is a very complex, column reaction process. It is not exactly like a column process, though, because to some extent, vegetation will cause materials to return upward against the flow of gravity via root uptake and translocation to shoots. This cycling phenomenon is very important in consideration of effects of acidity.

Effects in the Canopy

A number of potential influences of acidity in the canopy of vegetation have been hypothesized. These include direct effects such as:

1) SO_2 uptake via stomata leading to chlorophyll degradation, leaf injury, and decreased productivity;

2) dissolution of epicuticular waxes and production of lesions from acidic "hot spots";

3) accelerated cation loss from leaves.

The first of these is unequivocally damaging to natural vegetation and crops wherever these are located in an area fumigated by SO_2. The same is true for other gases such as ozone, hydrogen fluoride and PAN. The second and third direct effects are still largely hypothetical.

Indirect effects in the canopy generated by interaction between acidity and other factors include:

1) interactions with phytophagus insects;

2) interactions with pathogens;

3) interactions with pesticides;

4) interactions with other pollutants.

The evidence for all of these indirect effects is ambivalent. In general, enhanced acidity alters the native microflora of leaves which would seem to have an influence on invasion by pathogenic organisms. In general, plants of reduced vigor, for whatever reason, are more vulnerable to phytophagus arthropods. And almost any chemical reaction is sensitive to pH. Yet, there is no consistent field evidence at this time to support a general statement on the significance of acidity on these indirect effects. This does not mean that deleterious interactions do not occur under prescribed circumstances.

Effects in Soil

Excess loading of hydrogen ion on soils may lead to a number of complicated and interactive processes. In grossly abbreviated form, these are:

1) acidification of soils by hydrogen ion replacement of other cations on exchange surfaces;

2) mobilization of phytotoxic metals, most particularly aluminum and manganese as a consequence of soil acidification;

3) breakdown of clay minerals to forms of lower exchange capacity as a result of aluminum mobilization;

4) change in the composition or amount of soil meso- and micro-fauna, terrestrial algae, fungi, and bacteria resulting from soil acidification;

5) a decrease in biological functions such as mixing, decomposition, mineralization, and nitrification with acidification or elevated levels of aluminum or manganese.

Even a summarization of my assessment of all of these potential effects would take too long today. Instead, I will highlight some of the conclusions in the EPA report modified with some of my own interpretations.

1) The effect of anthropogenically-derived hydrogen ion is trivial on soils amended with lime, gypsum or fertilizer compared with the effects of these amendments.

2) Soils potentially affected by acid deposition are already acidic. They are generally non-agricultural soils. In most, but not all cases, the input of pollution-derived acidity is a small part of the acidification process.

3) In naturally acid soils, aluminum mobilization leads to leaching to lower horizons, or to groundwater, to surface water. Soluble aluminum may have toxic effects on vegetation and almost certainly plays a deleterious role in downstream aquatic systems.

4) Only on the most extreme sites (high elevation, subalpine forests, rocky outcrops of resistant terrains) is net acidification likely to occur over long times (several decades) with concominant declines in metallic ion supply, and alteration of microbial functions. These effects have not been demonstrated in the field.

Effects on Plant Growth

The influence of acid deposition on plant growth may occur through direct and indirect effects on shoots, or through changes in the soil. Further, influences of SO_2 deposition can be separated in the field only with difficulty from influences of wet deposition. All of these effects are complicated by other, often parallel, phenomena such as exposure to other gaseous pollutants (ozone, fluorides, hydrocarbons) and to heavy metals such as lead, zinc and cadmium. Whereas effects of acidity *per se* can be shown under controlled conditions, these effects can be positive or negative. Responses depend on species sensitivity, stage of plant development, and the nature of the exposure.

Considerable circumstantial evidence implicates acid deposition as the cause of extensive declines in some forests, notably spruce forests of northern New York and New England, and conifer forests of Germany. The

picture is complicated, however, by numerous disparities, and, as yet, there is no proof that acid deposition is responsible for these declines.

The bulk of evidence does not support the deleterious effect of acid deposition on crop plants except for the certain negative effect of SO_2 gas deposition.

AQUATIC SYSTEMS

Because aquatic ecosystems receive waters derived from land, intimate, biogeochemical linkages occur between characteristics of the terrestrial watershed and the enclosed aquatic system. The sensitivity of aquatic systems depends upon these characteristics together with atmospheric inputs. A list of major factors includes:

1) atmospheric inputs -- amount, composition, and temporal distribution;

2) terrestrial vegetation;

3) soil characteristics;

4) bedrock mineralogy and consolidation;

5) hydrologic flow paths and residence times of the watershed;

6) amount and type of peripheral wetlands;

7) alkalinity of the aquatic system itself;

8) alkalinity production by the biota, particularly in the sediments.

Thus, meteorologic, geologic and biologic factors play roles in how aquatic systems will respond to increased hydrogen ion loading. Predictions of whether or not lakes or ponds will change in chemical composition is a hazardous business in marginal regions. In general, excess acid deposition is titrated by the vegetation, watershed and lake or pond. If the capacity or kinetics of neutralization of the watershed and basin are insufficient to keep up with the loading rate, the alkalinity of a lake will decline and pH will drop.

Historical evidence for a decline in lake pH and alkalinity in parts of Europe and North America in the last three decades is convincing. The linkage between fossil fuel emission and lake acidification is entirely circumstantial and debated. I personally believe that the historical, geographic and chemical evidence is sufficient to accept that linkage. Others do not accept this relationship. In any case, sensitive bodies of water are located on crystalline or acid-metamorphic terrains in regions in which acid loading is high. What are the consequences of lake water chemical change?

Biological Responses

When pH's decline to between 6.0 and 6.5, and alkalinities decline to 65-35 meq/1 (EPA 1983), biological changes become detectable. Changes are gradual as pH descends still lower. Some changes are listed below:

1) changes in bacteria and fungal species with a shift toward more dominance by fungi;

2) shifts in species composition of phytoplankton, without, however, a necessary decrease in primary productivity;

3) diminution of diversity of macrophytes and a shift toward Isoetes, Nitella, Utricularia and moss species; there is not necessarily a decrease in primary productivity, nor is eventual dominance by Sphagnum inevitable;

4) extensive shifts in the structure of the zooplankton community occur with decreases in diversity common; zooplankton biomass may or may not decrease;

5) decreases or extinctions of large crustacea such as crayfish below pH's of 5.5; disappearances of mollusks occur below pH's of 4.9;

6) occurrence of fishes is reduced below pH 5.5;

7) changes in amphibians, birds and mammals are still speculative.

From a political point of view, it has been the sensitivity of game fish to acidity, particularly trout from naturally soft, oligotrophic waters, and the concominant increase in aluminum that has raised keenest public interest in this issue. Interest in the sensitivity of fish has led to extensive laboratory investigation. Three mechanisms have been proposed as responsible for disappearance of fish populations. These are:

1) decreased food availability and/or quality;

2) fish kills during episodic acidification (e.g., following snowpack meltoffs);

3) recruitment failure.

In most cases, recruitment failure seems to be the most common mechanism. This results, in turn, from either a reduced number of eggs spawned or higher larval mortality. It is felt that high hydrogen and aluminum ion concentrations interfere with normal calcium metabolism, particularly where ion exchange occurs around gills. Symptoms are edema, excess mucus secretion, and reduced hemoglobin and blood pH.

Regions of Vulnerability and Remedies

Lake acidification has only been observed on terrains of resistant rocks, in lakes of low initial alkalinity, and in regions of excess acid loading. Experts contributing to the EPA report suggested that an initial alkalinity of 200 meq/1 represented a threshhold for sensitivity to excess acid deposition.

Remedies for revising lake acidification are basically three: addition of basic substances such as lime to watersheds or lakes, fertilization of lakes with organic carbon or phosphate, and reduction of acid loading to levels below which the watershed-lake basin can neutralize incoming acidity. The first remedy is effective but expensive as a local solution. The second remedy is effective but expensive as a local solution. The second remedy is largely hypothetical and untested. The third remedy is likely to be effective as a large-scale solution but is costly to society as a whole.

HEALTH EFFECTS

Acid deposition has not been implicated as directly responsible for human health problems except in extreme cases where SO_2 gas or sulfate particles may cause difficulties for individuals with respiratory problems.

Concern has been raised about the indirect effects of acidification of soils and groundwater on the mobilization of lead, mercury and other metals. The EPA report discusses the correlation of mercury in fish with acid deposition and the possible increase in lead ingestion from drinking water in regions of acidified rain and groundwater. While such relationships may exist, there is no conclusive field evidence to firmly link increased acid deposition with such problems.

EFFECTS ON MATERIALS

The deleterious effects of polluted, urban atmospheres on some structural materials are well established and the contribution of acid substances is without question. Establishing the relationship between anthropogenic acid deposition and material damage from that caused by other pollutants is a difficult matter. It is thought that locally generated acids or acid precursors are more important than remotely derived substances, and that acidic "rain" *per se* is less important than dry deposition of gases and particles.

Perhaps the best-known damage is that to carbonate-bearing rocks such as concrete, marble, limestone or other stones with carbonate-cementing materials. Other materials susceptible to SO_2 gas, nitric acid vapor, sulfuric acid, and ammonium sulfate particles are metals, paints, masonry, paper, leather, textiles, textile dyes and glass. Higher humidities or wet surfaces significantly accelerate decay of these materials in the presence of acid substances.

According to the EPA report, the costs of material destruction to society, especially of cultural objects for which value is often beyond objective calculation, may be very large. In general, there are few satisfactory mitigative measures to be taken. Finally, it is extremely difficult to assess which proportion of total damage is caused by acidic substances themselves.

IMPLICATIONS OF ACID DEPOSITION FOR THE STATE OF ILLINOIS

Acid deposition is a proper concern for officials and concerned citizens of the State of Illinois. Illinois is subject to "acid rain" throughout the state, and local areas are subject to dry deposition of gases and

particulates. The areas of concern are different from those of New England states, however, because of the physical characteristics of Illinois.

While Illinois precipitation is acidic, it is less in volume than that occurring in the northeastern states. Thus acid loading, in general, is less. More important, though, is the fact that Illinois is not characterized by resistant bedrock and naturally acid soils. To the contrary, much of Illinois is covered with calcareous till and the sedimentary rocks underlying the state are generally rich in carbonates. Thus neither the soils nor lakes and streams are vulnerable to marked changes in pH, alkalinity, or aluminum concentrations. It is possible that there are some isolated pockets that are vulnerable but for the vast majority of the state, soil, groundwater and surface waters have ample alkalinity reserves to protect against centuries of hydrogen loading from pollution sources.

Much of Illinois is dedicated to tillage agriculture, and soils are typically limed if pH drops through agronomic manipulation such as nitrogen fertilizer additions. This liming practice counteracts acid deposition by about 100-fold.

Direct deposition on plants is another matter. "Acid rain" itself has not been shown to be deleterious to plants although under extreme circumstances lesions and indirect negative effects could occur. Of more concern, though, is the direct fumigation of vegetation, whether crops or naturally occurring species, by SO_2 and other gaseous pollutants. Some cost must almost certainly be accruing in localized areas of the state where major emissions occur.

The other major area of concern is the effect of acid rain and acid-generating gases on materials in urban and built-up areas. If an analysis of such exposures and damages now occurring has not already been made, it might well be recommended.

On one hand, Illinois' concerns for impacts of acid rain at the state level are largely of local nature and not of large-scale environmental significance. On the other hand, Illinois is a larger source than a sink, and as a member of a union of states, it must be concerned with effects of its effluents downwind. These effluents do have significant effects on other states which are not only sinks for Illinois' effluents, but they are more vulnerable to effects for geological and meteorological reasons. Illinois will be vitally involved in any remedial steps mandated by federal legislation to relieve the plight of the impacted states. For this reason alone, it is of great importance that officials and citizens of the State of Illinois be fully cognizant of all aspects of the acid deposition phenomenon.

DIRECTOR'S REPORT

Michael B. Witte, Director
Illinois Department of Energy and Natural Resources

To our misfortune, since the last annual conference we have observed how our climate has affected our everyday lives and our economy here in Illinois. For instance:

° Last December we saw extremely high levels of rainfall that, combined with the frozen ground, produced flooding along the major rivers in Illinois and caused extensive damage. Estimated Loss: $100 million;

° In May, at least a dozen tornadoes skipped across southwestern Illinois leaving one person dead, dozens injured and millions of dollars in property damage. Estimated Loss: over $20 million;

° Governor Thompson declared Kane, Will, DuPage and DeKalb counties as state disaster areas after heavy rains and flash floods flooded many homes and businesses; and

° This past summer a major heat wave and drought conditions for over two months caused many crop failures in the state, loss of life and extreme discomfort.

It will take a better economist than I to predict now the ultimate effects on farm income and consumer prices. I won't argue that these losses could have been totally prevented, but these examples attest to the need to improve our knowledge of, and ability to predict, short- and mid-term weather patterns. The staggering economic losses, as well as the loss of human life and human suffering associated with these weather extremes, argue forcefully not only for improved predictive capabilities, but for a commitment on the part of scientists to transfer data and information to public and private arenas. In turn, policy makers must strive to develop a technology for integrating into their decision-making processes the probabilistic information provided by scientists.

To be sure, foretelling future weather patterns is an imprecise science. As a group, meteorologists are one of the most maligned occupational groups on earth. This ingratitude toward the weather forecaster knows no national or cultural boundaries. In fact, in Poland they tell meteorologist jokes!

I live well out in the country and my neighbors are all farmers. Last spring over a beer in a local tavern, I was explaining some of the work of the Water Survey to one of these neighbors. His comeback harkened me back to Bob Dylon's famous lyric: "You don't need a weatherman to tell which way the wind is blowing." His actual remark--more to the point--was that he "doesn't need a scientist to tell if it's raining or not." But I expect that when I see him again this fall after harvest, he'll allow as how you might need a scientist to make it rain, or to make it quit raining, or to help you decide whether to plant or to go with PIK. He's had a particularly tough year.

Over the last two days, the various speakers have brought forward many research results dealing with our changing climate, weather and pests, climate and environmental quality, and acid rain issues. In addition, many interesting questions were introduced and remain to be answered. One point that was brought out repeatedly is that basic and applied research must be continually refined, integrated and carried out in the important area of climate. I think Stephen Schneider helped us focus more clearly on some arguments for public investment in this research.

The importance of gathering and interpreting data on the climate is reflected in the objectives and programs of this Department. The study of the state's atmospheric resource is an integrated program involving the scientific staffs of four of ENR's divisions--the Water Survey, Geological Survey, Natural History Survey and the Illinois State Museum. To some extent the atmospheric program is also linked to the programs of the remaining division, the Energy and Environmental Affairs division. It is customary in these annual directors' reports to provide some understanding of how our agencies have been addressing or will address some of the issues raised in that year's conference. Much of this has already been done for me by Messrs. King, Changnon, Wendland, Ruesink, Hendrie, and Semonin. Let me try to supplement their remarks with an overview of our efforts and capabilities.

The majority of this Department's atmospheric program is concentrated in the Water Survey. The climate program of the State Water Survey focuses on six important areas. The first of these is the provision of services, data and information--such as climate calendars and workshops--to all citizens and to industry, primarily agribusiness and energy concerns. The second area of focus is on the impacts of climate, and particularly effects of extreme events. Third is basic research into the climate systems that help produce the weather, and particularly the precipitation, in the state. Fourth is hydrometeorology to generate types of information that will allow us to wisely design and operate hydrologic structures in the state. Fifth is research and presentation of long-range outlooks which help us deal with the extremes of our climate such as droughts and floods. Finally, we are operating a major climate network to collect those data not available through federal agencies.

The meteorological program of the Water Survey is very strong also and feeds the climate program. We have basic research going on in cloud physics and dynamics including how raindrops grow and clouds precipitate; on how to modify the weather purposely and how to understand the ways that man is accidentally, through his cities and other endeavors, modifying the weather. Our research on the development and use of weather instruments to conduct major field programs provides us with unique information on how weather conditions develop in Illinois.

Illinois is the only state that has made a sizable long-term commitment to the study of its atmospheric resources. Climate is considered to be one of the state's basic natural resources. In 1980, Governor Thompson designated the State Water Survey as the Illinois Climate Center, and as such it has a staff of 40 atmospheric scientists dealing with wide-ranging forms of basic

and applied research. Some representative findings of this highly productive staff include the following:

- Climatological studies of severe storms in Illinois revealed that there has been a major state-wide increase in heavy rain day frequencies since 1960 with record-high frequencies in flash floods, contributing to the state's soil erosion problems. This trend could be seen in Stan's presentation yesterday;

- A two-year study of summer rainfall in the Chicago region provided new findings on urban and lake effects on summer precipitation and showed that the Chicago urban area creates conditions which increase summer rainfall by 15 percent over Lake Michigan; and

- A study of major dust storms that occurred in Illinois during the spring of 1981 determined that the storms were caused primarily by farm management practices such as fall plowing and extensive field work in the relatively dry spring.

Within the past year, the Water Survey's Analytical Chemistry Laboratory was ranked first among 27 laboratories throughout the world by the World Meteorological Organization for its accuracy and precision of chemical analyses on precipitation constituents. In addition, the Survey was selected from among 11 other institutions to serve as the Regional Climate Coordinating Office for a program under the National Oceanic and Atmospheric Administration. The Survey's four-year applied climate research project will serve as a model for national implementation.

Recognition of the importance of climate data collection and services is reflected in two new thrusts of our agency: A) the establishment of a statewide climate network to measure all atmospheric variables including wind, solar insolation, soil temperature and soil moisture around the state. This recognizes the state's need to monitor the climate resource beyond those data being provided by federal agencies; and B) the provision, in real time, of climate data and information through the use of computers and advanced telecommunications. The Climate Assessment System (CLASS) being established by the Water Survey, in concert with the Natural History Survey, will soon be operational. It will provide state agencies, county extension agents and private industry with real-time access to the current status of climate conditions across Illinois and with outlooks for future conditions. Included will be use of models of weather interactions with pests to allow for predictions of pest outbreaks. Yesterday Keith Hendrie provided a detailed look at some elements of the program.

The State Natural History Survey division of ENR has devoted its attention to the state's living natural resources. The Survey has studied the biological effects of weather and climate from several perspectives. These include changing climate and weather and their effects on species composition of natural communities, the likelihood of invasions by species not native to the environment, impacts on the yield of agronomic plants, climate effects on pests and diseases of plants and animals, climate effects on survival of wildlife, and effects of climate on migration patterns of birds and insects.

Service to Agriculture

Both the Illinois State Water Survey and the Natural History Survey have an absolutely unswerving commitment to applied research benefitting this state's agricultural community. It can be argued that the two greatest challenges to our agricultural industry are pests and weather.

Control of agricultural pests--insects, weeds and nematodes--requires massive expenditures each year by the Illinois agricultural community. Applied research to develop more effective pest control measures while maintaining environmental quality and the application through education of research results to production agriculture are both essential. The Department's Natural History Survey division is a leader in professional pest consulting. This important new agricultural industry in Illinois is kept up to date through the annual crop protection workshop and two Pest Management Scout Training schools held each year by the Survey. Natural History Survey researchers also devote much time to developing techniques and educational manuals that will allow farmers to do their own scouting for pests and will enable them to apply restricted use chemicals in a safe and cost-effective manner.

Perhaps the most important and uncontrolled variable affecting agriculture in Illinois is the weather. Most year-to-year variations in agricultural production and the ensuing certainty appear to be weather-caused.

Managing the atmosphere through varying technologies has long been a central goal of agriculture. The Water Survey has pioneered techniques aimed at allowing farmers to reduce crop variability due to weather. Water Survey hydrologists have made intensive studies of different chemical substances to develop means of reducing evapotranspiration from Illinois crops and farm ponds. For the past 20 years, Water Survey division scientists have been among world leaders in studies of ways to modify the weather. Survey scientists have used radars and aircraft to probe the atmosphere, attempting to define the types of clouds susceptible to change and the materials to use in clouds to produce rain or to suppress hail, principally for the benefit of Illinois agriculture.

While the separate capabilities and research interests of these two divisions--Water Survey and Natural History Survey--are impressive, in my mind the most exciting work--the area of opportunity for the future--involves integrating these individual capabilities to address the interaction of pests, climate and weather. In fact, few other research organizations in the country are attempting to systematically integrate knowledge concerning these two critical variables in the agricultural equation. Hence, we devoted an entire session of the conference on Monday to this subject. Our two major research efforts in this area were described in some detail by Bill Ruesink and Keith Hendrie.

In its own studies, the Natural History Survey is adding a new dimension to our knowledge of the effect of the quality of the atmospheric resource on non-human organisms. Some areas of investigation include:

1. Effects of plant-feeding insects: As discussed in this conference, host selection and rate of herbivory by feeding insects is affected by air

pollution. This impact is detectable at air pollutant levels below ambient standards and, furthermore, is in addition to decreased crop yields caused by the direct effects of air pollution on the physiological processes of the plants;

2. Effects of air pollution on the quality of fruits and forage: Although the evidence is not conclusive, it appears that in some cases air pollution affects the quality of the harvested portions of the plant and not just the quantity of plant production. Since the quality is more difficult to measure than quantity, this effect may be more pervasive than expected;

3. Effects of air pollution on susceptability to disease: It is well known that many ornamental plants are more susceptible to disease if the plants are under environmental stress, e.g., nutrient deficiency or drought. The effects of air pollutants are more complicated since stress conditions that close the stomata may reduce the toxicity effects. Furthermore, low levels of some compounds may satisfy some chemical demands by the plants. The conditions of benefits and negative impacts needs to be thoroughly investigated and described; and

4. Effects of air pollution on the genetic structure of populations: The selection of genetic characteristics in natural populations is affected by prevailing environmental conditions. Preliminary evidence suggests that air pollution can also impact the gene frequencies in some arrays of species, altering the competitive abilities of the species. The potential impacts of this phenomenon are virtually unknown, but obviously of enormous importance, especially in those plants which are of agronomic importance or in those plants which contain genetic diversity likely to be of pharmaceutical value.

From these remarks and this conference, our conclusion might be that many inherently interesting and economically consequential questions are before us.

Programs in Other Divisions

Given the subject matter of this conference, I have focused my remarks on two divisions of the organization. However, it should be obvious from Jim King's presentation on Monday morning that the Illinois State Museum occupies a central role in our efforts to understand climate, including the effects of Illinois' climate on the paleoecology of the state.

With a prehistoric, or even a pre-industrial ecological analysis, it is possible to examine and compare climatic changes at different periods in Illinois' past. With this valuable tool - the ability to compare - perhaps one can begin to separate out man's activities and their influence on climate.

It may be less obvious that the State Geological Survey and our energy-related programs in Springfield are climate-related. Much of the recent coal-related research at our Geological Survey is focused on minimizing the air quality effects of coal utilization. The newly established Center for

Research on Sulfur in Coal is integrating and coordinating coal-related research at major research institutions in the state. And our Energy and Environmental Affairs division in Springfield analyzes the immediate climate resources of solar energy, wind energy and hydropower as well as the intermediate climate-induced resource of biomass. As noted in yesterday's luncheon address, programs in energy conservation and solar energy can be viewed as a way of minimizing the as-yet-unknown future impacts of CO_2.

Climate obviously plays a major role in determining the energy use of our buildings, as we try to moderate between Illinois' freezing winters and hot and humid summers. The division plays an important role in educating the public and analyzing energy policies which help the people of Illinois adapt economically and comfortably to the seasons.

I would conclude my already-too-lengthy remarks with the following forecasts:

1. Understanding and predicting weather and climate changes, integration of this knowledge with other basic and applied sciences through interdisciplinary efforts, and transferring new knowledge to the decision-making arena will be even more important in the future than it has been in the past;

2. Illinois will probably continue to be in the forefront of these efforts. This is, however, a conditional probability; and

3. Scientific and lay interest in climate issues will grow in the next decade, as will the technical, legal and ethical issues posed by climate-related technologies which will inevitably develop and mature.

I am sure these forecasts are no news to you. But then--particularly after the excellent scientific presentations at this conference--you don't need a bureaucrat like me to tell which way the wind is blowing!

DIRECTOR'S REPORT

Jacob D. Dumelle, Chairman
Illinois Pollution Control Board

In the previous conferences, we used to give an annual report on our agencies and the environmental problems we face in the future. I don't think I can really talk too much about climate and matters of that sort. I do want to touch a little bit on this conference, but I want to end up in the traditional format and give you a couple of policy issues that my Board faces in conjunction with support by our sister agencies, ENR and the Illinois EPA.

I think as far as the acid rain situation is concerned, everybody is waiting for Bill Ruckelshaus to drop the shoe--I think he's supposed to do it this week--to see whether he goes with a four-state program which you saw just before lunch or if he goes with a 31-state program, or the 48-state program or some other combination. Depending on what Congress enacts, of course, out of all that may come some kind of a quota for Illinois. "You shall reduce your SO_2 and NO_x by so much by such and such a time." It'll be a national decision; they'll probably leave that reduction up to Illinois to work out among different sources, whether they're vehicles or power plants or whatever. I think at that point, then, my Board will have to go into action and have some rulemaking hearings with a proposal by the Illinois EPA and some research by ENR. It's an oncoming decision. If they go to the four-state program and it is those states we talked about earlier, it may not reach Illinois in the near future. We'll just have to see what happens.

I think the acid rain situation illustrates where Illinois is on many things, and where all the states are. The states have been traditionally reacting to federal initiatives on many things environmental, partly because you have to have uniform standards across the country to a large degree and if you don't, you get into competitive imbalances and things of that sort. I would just mention in passing that there are techniques that can be applied to existing burners and boilers to reduce NO_x emissions at fairly low cost, but again you get into one of these tradeoffs. It may change the ratio of the NO_x to the unburned hydrocarbons and aggravate the ozone problems. So we may be solving, to a degree, the acid rain problem and aggravating the ozone problem! We'll have to look at that soon and see if the research is good enough to guide us.

On the carbon dioxide and the "greenhouse" effect, I may have misunderstood one of the speakers. I think he was talking about a 16-meter rise in the oceans. I thought it was 16 feet, so that makes me more worried. On the other hand, he said it's 200 years away instead of 50 and in 50 years I'll be 108. Then I'd still be worried about it, but in 200 years I'm not going to worry about it. We'll see if we get a national decision out of this to curtail CO_2 emissions in some fashion and to get over to nonfossil fuel sources for energy.

I missed the morning session on the first day when this may have been mentioned, but one aspect of climate which nobody apparently has talked about at this conference is the whole business of the freon emissions and upper ozone layer depletion. Maybe this is because I've just seen some of the literature and I can't pretend to keep up with all the scientific literature. I've got transcripts to read and other materials on both rulemaking and contested cases. I did notice somewhere along the line that the latest research shows that the reaction constants are not as bad as they thought they were and they've revised it. Maybe the problem under study is largely disappearing, but it's another one of those things that we have to look at from a global stand point. It doesn't do much good if the United States bans freon and many of its uses (as it has) and Russia goes ahead and uses it. All our action does is buy some time, but the problem is still going to come to pass eventually. It again shows that we're all in this together and it's one ecosystem and we have to look at all of these common problems, whether it's CO_2 or freon or whatever it is.

Let me give you four policy decisions which face my Board, and indirectly affect all of you. What we try to do when we get into a particular rulemaking is to make sure that we're looking at the whole forest. We try to step back and say that what we do here may be a precedent and do it knowingly. You can make a decision by just floundering into something, or do it without realizing that you're doing it and then you're held to that. "You did it for so and so. Why can't you do it for me or for the rest of the state?"

The first policy decision involves the use of Illinois coal. That's always a very important subject because of the 14,000 miners in Illinois and the big resources here. Of course, all of you know how important it is to the economy. What's happened is that the state, through the various conversions to gas and the use of nuclear power and the use of Western coal, has brought the sulfur dioxide content of the air far below the health effects level, the 0.03 parts per million annual standard for example, and now there's room to go back up. You can't exceed that standard because then the federal government gets nervous and starts putting sanctions on you like taking away your highway money or your construction grant money or program money. But there is air quality room and we have a procedure where any industry, any source, can come in and ask for what we call a "site-specific" rulemaking to use higher sulfur coal, hopefully Illinois coal. We currently have six particular industries or municipal power plants before us on that: CPC International, Olin, Alton Packaging, Winnetka Power Plant, the CILCO plant down in Peoria and General Tire in Decatur. All of them want a site-specific regulation to go to a higher sulfur content.

Now assuming that the meteorological modeling is reasonably acceptable and thorough and that it is not the question. The policy issue is "how much of that capacity in the air do we give to that particular source?" Do we give it all? Do we go right up to the health standard, which then means that there is no room for any further industrial development generating even any sulfur emission. Or do we give it for a limited time, like a five-year period and then say, "We'll take another look at it in five years and you'll have to go through another rulemaking." I think that's a particular policy

issue because it could affect future Illinois industrial growth. The Board has tentatively said--it's subject to a vote at our next meeting on the 23rd--that they don't want a time limit in the rule. They don't want a 5-year rule or a 10-year rule. They would prefer to have an indefinite rule, which is the way most of our rules are--without time limits on them, but reserve the right if a new industry came along they could go back and take a look at that rule and rephrase it. Perpaps some language will be put in the Board's opinion that that particular industry or utility should not make a very long-term commitment like a 20-year coal contract or should not buy up a coal mine or something of that sort. That's one of the issues that we will be deciding very quickly.

A second issue is a package of issues and I can't go into detail on them but they involve hazardous wastes. I started to talk about the various peaks and hollows in the attitude of the public toward the environment. When my Board started up in 1970 and the Illinois EPA was created, we were at a definite high point in the public acceptance and desire for environmental control. For the next couple of years it stayed that way. Then from about '73 to '75 we were into a low. We had a lot of legislation coming in, a lot of controversy about sulfur dioxide standards and things. We've weathered all of that, and public feeling is coming back up again. It's not quite to where it was in 1970, of course, when we used to have reporters and television cameras at each of our weekly Board meetings, but I think that you can tell that it's back up. Part of the reason is the reaction to the dioxin situation, part of it is the reaction to Wilsonville and Love Canal and "acid rain." I think those examples taught this half a generation which has come on the scene since 1970 that there are environmental problems and there are natural limits and we can't go beyond those limits without something happening.

Because of those examples nationwide and because of some of the Illinois experiences, a number of bills have been passed. There were 25 amendments to the Illinois Environmental Protection Act this session and we're waiting to see what the Governor does on each of those. In some cases my Board has suggested different language to smooth out things without changing the intent of the legislation, and I know the Illinois EPA has suggested language changes. In the next two weeks the Governor will be signing these bills. Some of them ban hazardous wastes for different types--liquids; different dates--1984, 1985; and most of them require rulemaking by my Board with input from both Mike's department and Del's agency. So very soon new rulemakings will be coming along on hazardous wastes.

Part of the problem in the policy decision is not only how fast do you ban something, but how do you get the whole economy turned away from landfills (which are cheaper, generally, than incineration or chemical fixation or neutralization or something of that sort)? And how do you assure yourself that you don't get bootlegging and midnight dumping? There are a lot of administrative problems with turning a major state around and getting away from putting stuff in the ground where it doesn't change and just sits there and waits for a leak in that clay lining and maybe it can cause a problem 30 or 50 years from now.

The third policy question that we're going to have coming to us very soon is in the statewide water quality standards revision, with which ENR has helped by doing a lot of the research. The Illinois EPA is about to submit it to us and we're going to go through each of the 18 watersheds in Illinois and hopefully get tailored water quality standards which go with both the natural limits and economy. Back of all that is going to be the central question; "what is the worth of a mile of river suitable for fishing or suitable for swimming or whatever other use you want?" This is, I think, a legitimate question. I don't think we can answer it within the limits of the Clean Water Act, which says you shall enhance water quality and make it fishable and swimmable--it stills says--"wherever possible," and that means economics.

We had a rulemaking proceeding involving Galesburg--which is not yet finished--but it came down to $40 million more for Galesburg, even if 75 percent were federal money, and maybe it would bring up water quality on four miles of river. I said, "I don't think it's worth $10 million dollars a mile for that river," and tentatively the Board is going ahead and letting Galesburg get out of that particular requirement. You can always look at it again in the future and make them do it later if the economics change. We'll have to do these case by case and get a feel for it. I think we have to look at the economics. It's not the same as air pollution where you have absolute health standards at the federal level and you can't breach them. You don't have to get into what a life is worth. You <u>can</u> get into what a mile of river is worth.

The fourth policy question is "what should be our policy on environmental research?" I think when you look at this conference, you have had some very thorough research on CO_2, very thorough research on acid rain. People are beginning to accumulate 30 years or so of CO_2 data, or 5 or 6 years of acid rain data and that's very valuable. I was trying to make a connection between what some of the speakers were saying and the specific environmental research that I would like to see done, and it occurred to me that some of the things such as the discussion on aphids and the discussions on cutworms are not just Illinois problems. Those aphids must affect corn or other plants in Iowa or Indiana or Wisconsin. Yet we in Illinois are studying those things and I'm sure some of those findings will have national impacts.

I think what we've done for a long time is that we've always waited for the federal government to study environmental problems on, say, Lake Michigan. If the federal government with its research cutbacks doesn't study Lake Michigan, we don't. I think we're going to have to look at some of those subjects: maybe it's the asbestos in Lake Michigan, maybe it's the zinc and cadmium inputs to Lake Michigan from the air, maybe it's such a far-out thing as non-ionizing electromagnetic radiation. We should be looking at environmental problems that affect Illinois citizens, not always waiting for the federal government to do research. Try to get them to do it, of course, if we can but--just as we're doing on the aphids and cutworms--begin to look at problems and act, not react. We have a duty to protect the Illinois environment and especially public health. Thank you very much.

DIRECTOR'S REPORT

Delbert D. Haschemeyer, Deputy Director
Illinois Environmental Protection Agency

Aside from the role that the director, Mr. Carlson, plays in advising the National Governors' Association and aside from the role that some of our staff people, and Dan Goodwin in particular, play in the STAPPA organization which is the national organization of State and Territorial Administrators of Air Pollution Control Programs, our agency really does not have a formal program which is addressing the acid rain issue or is looking at climate. That's not to say that we're not aware of climate and the impact that climate can have on the State of Illinois. If we were not aware of that, we certainly became acutely aware of it this summer as we watched the ozone monitors in Chicago.

Accordingly, I thought what I would do is spend a few minutes and provide a brief status report on some of the regulatory activities occurring or about to occur in the state at the current time and then spend a couple of minutes looking at another climate in Illinois, one that I tend to characterize as a regulatory structure climate or a regulatory climate.

The major regulatory activities ongoing at the moment include activities to secure final authorization under RCRA for the hazardous waste program, activities to secure authorization to administer and implement the deep well injection program under the Safe Drinking Water Act, activities to develop an I and M, automobile inspection and maintenance, program to avoid sanctions under the Clean Air Act, regulatory initiatives which may be necessary under new legislation which has been enacted by the General Assembly this past session, and activities at the current time that are being pursued to secure the benefits of CIRCLA, better known as Superfund, for the State of Illinois.

Starting with RCRA. The Illinois hazardous waste management program has undergone significant change over the course of the last two years. These changes are primarily the result of the state assuming more responsibility in the implementation and enforcement of the comprehensive hazardous waste management program developed by U.S. EPA under the Resource Conservation Recovery Act of 1976. Subtitle C of RCRA (which is the Resource Conservation Recovery Act) requires U.S. EPA to adopt regulations which set out a comprehensive national hazardous waste management system. Subtitle C also provides that states may be delegated authority to implement a state hazardous waste program which is equivalent or substantially equivalent to the U.S. EPA-defined program.

The initial round of regulations was adopted by U.S. EPA in May 19, 1980, a couple years late. These regulations and their subsequent amendments provide not only substantive standards for generators, transporters, treaters, storers and disposers of hazardous waste, but they also set out a two-phase process for the delegation of interim authorization to the states to implement the RCRA program. They also set forth the requirements which the state

needs to meet in order to be granted final authorization under RCRA. In order for a state to be delegated Phase II of interim authorization, it has to demonstrate that its permitting requirements are substantially equivalent to the RCRA requirements. Interim authorization, as its name implies, is only temporary U.S. EPA approval of the the state program. U.S. EPA grants interim approval, interim authorization, with the implicit assumption that the state will work towards final authorization. Whereas a state has to demonstrate to U.S. EPA that its hazardous waste management program is substantially equivalent to the federal program in order to be granted interim authorization, in order for that state to receive final authorization from U.S. EPA, it has to prove that its program is equivalent to the federal program. Presumably this means that there is to be a greater degree of uniformity between the state and the federal programs.

Following the passage of Public Act 82-380 and adoption by the Board of the rules proposed from PCBR 81-22, which are virtually identical to the federal RCRA regulations found in 40 CFR parts 260, 61, 62, 63 & 65, the State of Illinois was granted Phase I of interim authorization on May 17, 1982. The Board adopted amendments to those rules which became effective March 4, 1983. Following the amendments, the Agency met with U.S. EPA to determine what was necessary to secure final authorization. U.S. EPA identified certain statutory problems which must be corrected prior to any grant of final authorization. Of particular concern to U.S. EPA were the provisions of the Environmental Protection Act which would allow a RCRA permit to be issued by default if, in the event of a RCRA permit denial appeal, the Board would fail to take final action within 90 days of the filing of the petition. Similarly, U.S. EPA was concerned about the provisions of the Act which allowed a variance to be issued by default if the Board failed to render a decision within 90 days. It was a position of U.S. EPA that RCRA permits and variances could not be granted by default. Consequently the Board, the Agency and other parties sought the necessary amendments to the Environmental Protection Act this past session of the General Assembly. These amendments were continued in Senate Bill 815 which was passed by both houses and now awaits the Governor's approval.

We are currently in the process of preparing an application for final authorization under RCRA. I expect that we will submit a draft version of the application to U.S. EPA before the end of this year. U.S. EPA will in turn provide preliminary comments on the content of that submittal. In March of '84 the Agency will be conducting a public hearing and after responding to public comments received at the hearing, the Agency will submit a final application to U.S. EPA. Within 180 days after we file the completed application, U.S. EPA must either grant or deny the state's request for final authorization. During this 180-day period, U.S. EPA will conduct its own public hearing on the application. At the current time, we expect that the State of Illinois will be granted final authorization before the end of 1984.

The UIC program. The Agency is also presently seeking U.S. EPA approval which is called primacy under the Safe Drinking Water Act for the state Underground Injection Control program. The Agency submitted an application for primacy in January of 1982. Unfortunately, U.S. EPA approval of the state program was delayed due to the same deficiencies that were raising

problems with the RCRA program. Once again Senate Bill 815 appears to have addressed this. In anticipation of the passage of Senate Bill 815, U.S. EPA has scheduled a public hearing on the primacy application. This is the last major step in the approval process. The hearing will be held on September 21, 1983 at 10:00 a.m. in the studio of the Agency Springfield office. Barring any problems we expect primacy before the end of this year.

Turning to the I and M program. Following a long-standing disagreement with U.S. EPA regarding the Federal Clean Air Act requirements for Illinois to have and administer an I and M program, that is an automobile inspection and maintenance program, U.S. EPA in a notice of proposed rulemaking published in the February 3, 1983 Federal Register indicated that they intended to proceed with sanctions for the State of Illinois for failure to implement the state's '79 implementation plan which required an automobile inspection program. The potential sanctions under the Clean Air Act for the State of Illinois are the withholding of federal highway funds for those areas not meeting the national ambient primary air quality standards. In Illinois this is estimated to be in the range of $300 million a year. This is the big stick that U.S. EPA carries. They can also withhold the Section 105 program grants under the Clean Air Act. These are the grants that fund more than 50 percent of the state's air pollution control program. Thirdly, moratorium on the construction of any major new air emission source in the non-attainment area. And the fourth potential sanction is the withholding of sewage plant construction grant funds for the construction in the non-attainment area. This one has not been costed out; it's discretionary with the administrator but potentially represents millions more.

Following the February 3 notice, the state engaged in a number of activities and explored a number of options including legal action, political action, legislative actions, and it concluded that none of these options was very attractive and would probably not be productive.

In June Ruckelshaus announced that U.S. EPA would drop its plan to impose sanctions in most of those areas in question excepting those which required inspection and maintenance programs according to the Clean Air Act. This included Illinois, which made I and M a part of its '79 implementation plan. Illinois became one of 11 states which Ruckelshaus indicated he planned to proceed against. A few weeks later the new administrator met with Governor James Thompson to discuss the state's position on inspection and maintenance. Just prior to this meeting, Utah Governor Scott Matheson had tried the same thing and, according to press reports, Ruckelshaus indicated U.S. EPA was prepared to impose sanctions in that state in a move to bring it into compliance on the I and M issue. Faced with the possible loss of millions of dollars in federal highway funds plus other aspects of such sanctions, Governor Thompson told Ruckelshaus that the state would resume its efforts to institute an inspection program with the understanding U.S. EPA would not follow through and carry out its threat of sanctions. Under those conditions, an agreement was reached in which U.S. EPA would not take final action on withholding federal funds.

On August 3, a notice of proposed rulemaking appeared in the Federal Register to announce the beginning of the mandatory comment period on withholding part

of the federal grant for the state's air pollution program. Under the formula proposed by U.S. EPA, the state would lose 60 percent of its annual federal grant if a mandatory I and M program was not started. This represents about $2 million a year or about 45 percent of the state's air pollution control budget. To avoid this funding loss, the Agency is in the process of putting together an inspection program and will soon have to start pushing it along the political approval path.

There are many options in putting this program together and they include many and various complications or compilations of possibilities of costs and benefits, etc. These options include frequency of tests, nature of the test itself, the vehicles tested, geographic areas covered, who administers the test, how the expenses will be paid, the amount of emissions reduced, the starting date of the program, and so forth. We are currently in the process of developing comments to the August 3 Federal Register and we should be submitting those on or before September 19. While it's too early to make any firm predictions as to what the program will be or what it will look like, the program will undoubtedly require legislation. This will be developed and introduced next spring unless for some reason currently unknown or unexpected a special session would be required. Board rules, if necessary, will probably be developed and submitted to the Board late this fall or early winter. At the moment, the earliest anticipated date to have the program up and running appears to be sometime in 1985. Needless to say, there still remain ample opportunities for the fragile agreement to come apart and the consequences, whatever they are, to occur.

Turning to new legislation and other anticipated rulemaking, Senate Bill 659 requires the Board to adopt standards for certification of personnel. House Bill 1108 and House Bill 1257 require the Agency to recommend to the Board a permit and inspection fee schedule for hazardous waste disposal sites requiring a RCRA permit. The schedule is to be filed by January 1, the Board is to adopt it by March 1, 1984. House Bill 1257 requires the Board to adopt regulations which establish a hazardous substance plan. This is expected to be the state equivalent of the national contingency plan under CRCLA or Superfund. House Bill 1257 also requires the Board to adopt procedures for the review of an Agency decision to take response action under that bill. In addition, House Bill 1257 requires the Agency to establish procedures for the collection of hazardous waste disposal and treatment fees. The procedures must be adopted by the Agency by October 1, 1983. Unless the Agency is able to adopt and file these procedures as emergency rules, it will be impossible to meet the statutory deadline, and as a practical matter, it's impossible to meet it even if we do. It should also be noted that if the Governor vetoes or amendatorily vetoes House Bill 1257, the October deadline will come and go before the bill ever becomes law.

House Bill 1054 requires the Board to adopt regulations which prohibit or set limitations on the type, amount and form of liquid hazardous wastes that may be disposed in landfills. House Bill 1054 requires the Agency to submit a list to the Board and ENR of liquid solvents which pose a threat to the environment, the list to be submitted October 1, 1983. October 1 is a busy date!

The Board is to adopt regulations by December 1, 1984 which prohibit or set limitations on the type and amount of liquid solvents that may be disposed on land and we're to prepare the initial lists. 1054 also requires the Agency to submit a list to the Board and ENR of nonliquid hazardous wastes which pose a threat to the environment, the same procedure to be followed. House Bill 267 requires the Board to adopt regulations relating to establishing performance bonds or other securities for non-hazardous waste disposal site which required a permit under section 21D of the Act. I've got other regulatory activities listed but the intent of that section was to give you a flavor of the regulatory burden that the General Assembly feels that our respective agencies should be carrying out.

Superfund activities. Superfund can support three types of activities, immediate removals when a prompt response is needed to prevent harm to public health or welfare or the environment. For example, immediate removals may be ordered to avert fires or explosions, to prevent exposure to acutely toxic substance, or to prevent a drinking water supply from contamination. Planned removals. When an expedited but not necessarily immediate response is needed, these actions are intended to minimize increases in danger or exposures that would otherwise occur if responses were delayed. Remedial actions, which are longer term and are usually more expensive, aimed at permanent remedies. They may be taken only at sites identified on the national priorities list. Our people tend to refer to these three categories as the immediate removal being a screaming emergency, the second one being an emergency and third one being maybe an emergency.

Before Superfund dollars can be spent for cleaning up designated waste sites, Illinois must provide certain assurances through a cooperative agreement or state contract negotiated between Illinois EPA and U.S. EPA, and we must assure that the state will assume operations and maintenance responsibility for the site for all clean up, contaminant removal and remedial measures that are implemented. We must provide a facility for off-site treatment storage or disposal of waste, if necessary, and we must share in the cost of the remedial action. Under CIRCLA, the amount of the state's payment would depend on ownership of the site at the time of disposal. If the site is publicly owned, the state must pay up to 50 percent of all remedial cost actions. If the site is privately owned, the state must currently provide 10 percent of all remedial action costs. Under certain emergency conditions, remedial response is all federally funded.

Costs of remedial work at problem sites in Illinois are likely to total in the millions of dollars. Our current estimate for those that made the national priorities list is something in the range of $55 to 70 million. Therefore, even a state match of 10 percent can result in a substantial outlay of money. Funding resources at the state level will largely be limited to the Illinois Hazardous Waste Fund which, hopefully, with the passage of House Bill 1257 and the approval by the Governor and concurrence by the General Assembly will provide those funds.

In '83 Illinois moved rapidly to define and develop a state program to work with U.S. EPA on Superfund activities. Under guidance from Region 5, Illinois has identified and evaluated candidate waste sites to become part of

the national priority list of 418 sites targeted for early Superfund action. Thirty-two potential sites were submitted for inclusion on the list. Eleven were selected by U.S. EPA. The 11 sites were Greenup A & F Materials in Cumberland County, Wauconda Sand and Gravel in Lake County, Marshall Velsica in Clark, Waukegan Outboard Marine Corporation in Lake County, LaSalle Electric Utilities in LaSalle, Penbrooke in Kankakee, Waukegan Johns-Mansfield in Lake County, Galesburg Coppers in Knox County, Byron Johnson in Ogle County, Morristown Acme Solvents in Winnebago County, Belvidere in Boone County.

Last year the following Superfund activities were accomplished:

- Development of cooperative agreements between U.S. EPA and Illinois EPA to do work at Byron Johnson, Penbrooke, Morristown and Greenup A & F.

- Selection of contractors and implementation of remedial investigation feasibility studies. One thing Superfund has given us is another whole list of acronyms. That's a RIF, and that's required under CIRCLA.

- Selection of contractors to do remedial investigations also expect to be completed in the very near future for Morristown Acme, and Greenup at A & F facility.

The state lead work in the future. We'll take the lead and sign cooperative agreements for completing the RIFs and procure contractual services for studies to be completed in the first half at Byron and Penbrooke. Construction, which is the Superfund term for removal, will be initiated at Byron and Penbrooke. Remedial investigation feasibility studies will be completed at Morristown and Greenup. Also we will have entered a state contract for Waukegan and Wauconda to complete the RIFs through a U.S. EPA contractor during the first half of fiscal '84.

That brings me to the last topic that I want to touch on just briefly, what I call the Illinois regulatory climate. The Illinois climate for environmental regulatory initiatives can be described, I think, as good and bad. It probably doesn't differ very much from the national climate. The good news is that there continues to be strong and public growing awareness and support for environmental protection. All the polls in recent years show a strong public support for protection of the environment even if it means more regulations and more costs. Further, this support appears to be uniform across political affiliations, economic status, ethnic and social groups. It's particularly encouraging when, with the exception of the environment and perhaps one or two other areas, there appears to be strong public support for reducing the overall regulatory burden imposed on today's society by all levels of government. The strong public support for protection of the environment, I think, can be attributed, at least in part, to the fact that there is a recognition that, in the long run, protection of the environment is necessary to protect the health of our children and grandchildren.

The bad news is that the resources are not plentiful and they are not likely to become plentiful in the foreseeable future, at least not in the next few years. The growth that has occurred in the environmental program during the '70s in Illinois, for the most part, was funded by federal funds, principally

program grants under the Clean Air Act, the Clean Water Act, the Resource Conservation Recovery Act and the Safe Drinking Water Act. Federal funds available this past year and in the foreseeable future as this country struggles with record deficits will probably, with an inflation factor, not maintain the current level of effort. The number of agency employees has gone from a high of 809 in fiscal year '80 to a current level of about 670.

As indicated by my earlier status report in the regulatory activities, the environmental regulatory programs of the state continue to expand and add responsibilities to all of the environmental agencies in Illinois. What this means, I think, is that in the future we're going to do more with less. We're going to have to be more efficient.

In 1970, the Illinois Environmental Protection Act was passed creating the Environmental Protection Agency, the Pollution Control Board and the Institute for Environmental Quality which is the precursor at least in part to Mike's operation. The Agency was given a primary responsibility for implementing the state's environmental policy by administering the various programs through the permitting system and inspection, monitoring, sample collection, analytical work, enforcement, and so forth. The Pollution Control Board had the primary responsibility for making public policy through its rulemaking authority. It was also anticipated that the Board would be acting as an environmental court by exercising its quasi-judicial authority. The Institute for Environmental Quality was to serve as the environmental research arm of the state and was to assist the Board and the Agency in execution of their responsibilities. These three agencies were to establish and implement the environmental programs in Illinois.

I think it's fair to say that in the early '70s the three agencies did what they were intended to do and did a reasonably good job. However, since that time, there have been a number of amendments to the Environmental Protection Act and circumstances have substantially changed from those existing in the early '70s. Today there are at least five other entities that play a role in the development of environmental programs in Illinois. They are U.S. Congress, U.S. EPA, Illinois General Assembly, the Attorney General, and the Joint Committee on Administrative Rules. There may well be others. Today most major, environmental policies regarding Illinois programs are not made by the Agency, the Board or the Institute. The decisions are made in Washington - what the program will be by Congress and U.S. EPA, and in Springfield by the General Assembly - whether the state will implement the programs. More and more frequently new legislation provides for the rolling through of federal regulatory structure with language which provides that such regulations shall in substance be identical, or language to that effect. In addition, we are frequently seeing more language that says something like "such regulations shall be no more stringent than the federal regulations."

With that kind of enabling legislation, we are looking now at nothing more than an editorial administrative process for placing the federal regulatory structure in the Illinois Register as the Illinois rules. While public hearing requirements and the like may apply, they are in a large part, at least from the perspective of having a substantial impact on the rules, academic and counter-productive to quick, efficient adoption of such rules.

I'm not arguing or suggesting that the roll through of federal regulatory structure is inappropriate. Indeed, I think there are sound public policy reasons for doing so. But it does raise some questions. For example, what's the best regulatory structure for accomplishing the goal of adopting existing or proposed federal programs? If I may speculate for a moment, there is at the current time a good deal of debate going on in Washington and around the country on the acid rain issue. A number of bills have been introduced and others are apparently on the way. The only possibility that I see for the state to have a voice in determining what that policy will be is if the legislation or the amendments--assuming that some is going to be passed and I think there will be--provide for some state flexibility in determining how the reductions, whatever the reduction target is going to be, are going to be achieved. Right now, I would not hazard a guess as to whether the state will have that flexibility. Based on past acts by Congress in the past few years, I would not be optimistic that there will be a whole lot of flexibility at the state level once that legislation is passed.

Let me touch another area of confusion which I think exists. This is sometimes raised as the issue of Agency rulemaking versus rulemaking by the Board. In my opinion this issue is a straw man. This issue has arisen at least in part by adoption of the Illinois Administrative Procedures Act which among other things defines a rule as "each agency statement of general applicability that implements, applies, interprets or prescribes law or policy." Thus, under the Administrative Procedures Act, design criteria, opinions, permits, etc. are rules. Prior to the Administrative Procedures Act, the items were simply considered guidelines for interpretation of Board rules or simply an opinion or a permit decision. Today a guideline or the Agencies advising someone of its interpretation or its opinion regarding a Board rule or provision of the Act means that we have adopted a rule under the Administrative Procedures Act. We are once again into the quagmire of whether or not we have infringed on the Board's jurisdiction in adopting rules or whether the Board has lived up to its responsibility in adopting rules. I'd suggest to you that that issue is really not an issue. You simply have to understand that what is happening is people are comparing apples and oranges and the two do not equate.

Let's touch another area, enforcement. Under the law the Attorney General is the attorney for the Agency for all enforcement cases. It is further the Attorney General's position, and he may well be correct, that the Attorney General has exclusive right to determine what cases will be pursued, when they will be pursued and how. The state's been fortunate that at least since 1970, the Attorneys General from Bill Scott to today's Neil Hartigan have had a strong interest in the environment and have committed a fair amount of resources to pursuing and prosecuting environmental cases.

However, it's also historically true, and remains true today, that the Attorney General's interests in resources give priority to those environmental cases involving issues with high public interests. This frequently does not include cases where the issue may not be the public's number one concern such as the failure of a public water supply to have a certified operator or the failure of a facility to have the appropriate permits. It is true that these

are not sexy cases, yet in terms of protection of the public health, a certified operator at a public water supply may be critical. A permit may be critical to ensure that a facility once built can and will operate in compliance with the law. Both cases represent situations where an ounce of prevention may well be worth a pound of cure.

In the past few years there have been several amendments to the Act to strengthen enforcement options and to meet the criteria necessary for delegation of authorization of federal programs. Almost all of these have expanded and strengthened the possibilities of criminal prosecutions. Today the Department of Law Enforcement is devoting resources to the investigation of potential criminal conduct involving hazardous wastes. There are many other issues involving enforcement including time frames, resources to prosecute a case, willingness to impose a substantial penalty and so forth. All of these issues, I think, suggest a need to evaluate the enforcement process and perhaps to consider concepts including administrative orders, arbitration and any other possibility. In short, how do we get the most effective enforcement for the dollars we spend?

Compared to 1970 the regulatory climate today is more complex, more crowded, more difficult and I think in many respects less efficient. Given the substantial change in the regulatory climate that has occurred since 1970, perhaps it's time to review the total environmental regulatory structure in Illinois to try and determine whether it is the most desirable, most efficient, and most acceptable regulatory structure for the 1980s and 1990s. Thank you.

BIOGRAPHICAL SKETCHES OF SPEAKERS

Carl S. Barfield

Carl S. Barfield is an associate professor in the Department of Entomology and Nematology at the University of Florida, a position he has held since 1981. He came to the University of Florida as an assistant professor in 1976 following the receipt of his PH.D. in entomology from Texas A&M University. He received his B.S. in mathematics from East Texas Baptist College in 1970 and his M.S. in biology from Stephen F. Austin State University in Nacogdoches, Texas in 1972.

Dr. Barfield's current research is focused on the investigation of the biology of the fall armyworm and the velvetbean catepillar. He also instructs in integrated pest management and is working to provide Spanish-language training materials for crop protection to Honduras and Ecuador. Dr. Barfield has worked for a number of international, national, regional, state and local agencies. He spent over eight months in Latin America viewing and advising crop production schemes for plantation and small farm agriculture. He served on an Interagency Personnel Agreement with the U.S. Department of Agriculture/SEA-CSRS for four months in 1981 to work on a large proposal to study insect migration. He consulted for the Consortium for International Crop Protection in the design and implementation of integrated pest management programs in Belize, Barbados, Jamaica, Mexico and Guatemala.

Dr. Barfield has authorized over 35 scientific papers and has a nationally published syllabus for a course in "Understanding and Implementing Pest Management Strategies in Agricultural Systems."

He is a member of the Entomological Society of America, the Entomological Society of Canada, the Florida Entomological Society, the American Registry of Professional Entomologists with certification in Ecology/Population Dynamics, the National Geographic Society, Sigma Xi, Alpha Chi National Honor Society and Beta Beta Beta.

Stanley A. Changnon, Jr.

Stanley A. Changnon, Jr., has been chief of the Illinois State Water Survey since 1980. He served from 1954 to 1968 as the climatologist on the staff of the Illinois State Water Survey. He was head of the atmospheric sciences section from 1969 to 1979 and is also a professor of geography at the University of Illinois. He has authored more than 250 scientific and technical papers and reports concerning meteorology, climatology, and water resources. One hundred forty-five of these have been published in various scientific and technical journals.

For a paper he co-authored, he was chosen by the American Geophysical Union as the 1964 recipient of the Robert E. Horton Award presented for the most outstanding paper in hydrology published in 1964. Another paper was recognized by the Building Research Institute in 1966 as a Scientific Contribution

to the Science of Building, and a 1976 paper was awarded the best of the year in the Water Resources Bulletin by the American Water Resources Association. The American Meteorological Society awarded him the Cleveland Abbe Award in 1981 for outstanding research contributions.

Mr. Changnon obtained his bachelor of science degree with honors from the University of Illinois in 1951, and obtained his M.S. from the same institution in 1956.

He is a member of Sigma Xi, Pi Mu Epsilon, Illinois Academy of Science, American Geophysical Union, American Association for the Advancement of Science (past secretary of Section W), Weather Modification Association (past president), American Association of State Climatologists (president), and the American Meteorological Society (AMS). Mr. Changnon was also chief editor of the Journal of Applied Meterology. Because of his contributions to the atmospheric sciences, he was chosen to be a Fellow of both the AMS and AAAS. He was also elected Councilor in the AMS in 1974.

Jacob D. Dumelle

Mr. Dumelle has been chairman of the Illinois Pollution Control Board since 1973 and was a member of the original Board appointed in 1970. The Pollution Control Board does all environmental rulemaking in Illinois and adjudicates contested cases (enforcement, variances and permit appeals). Mr. Dumelle holds a B.S. in mechanical engineering and an M.S. in public engineering administration, both from the Illinois Institute of Technology, and is a registered professional engineer in Illinois. He was the former city manager of Lebanon, New Hampshire and was assistant to the manager of Brookfield, Illinois and Peoria, Illinois. He has also served with the federal government and with the Metropolitan Sanitary District of Greater Chicago as an assistant chief engineer.

Mr. Dumelle has written more than 50 articles and reports on the environment or on governmental administration. In 1975 he received the Environmental Quality Award from the U.S. Environmental Protection Agency-Region V, and in 1980 he was the recipient of the 10th Anniversary Earth Day Award from tne Illinois Environmental Council.

Delbert D. Haschemeyer

Delbert Dean Haschemeyer, a native of Golden, Illinois, in Adams County is deputy director of the Illinois Environmental Protection Agency. He received his B.S. from Western Illinois University and his law degree from Valparaiso University. While at Valparaiso, he was a member of the Law Review Editorial Board, serving as business manager for the Law Review. Prior to joining the Illinois Environmental Protection Agency in 1974, Haschemeyer was an assistant attorney general with the Illinois Attorney General's Office, in Springfield, Illinois, and previously served as a technical advisor for the Illinois Environmental Protection Agency. Before that Haschemeyer was with the

Peoria law firm of Heyl, Royster, Voelker and Allen. Haschemeyer is a member of the Illinois Bar Association and is licensed to practice law in Illinois, Indiana and before the Federal District Court of the Southern District of Illinois.

L. Keith Hendrie

Keith Hendrie was born in Australia, where he attended the University of Adelaide. His main research projects there were a case study post-synoptic analysis of the meteorological phenomena during an unusual extended period of summer precipitation and their impact upon man, agriculture and the landscape; and a micrometeorological study of the temporal and meteorological factors influencing the radiation fluxes above and within a eucalypt forest, and their relationship to vegetation structure and productivity.

In 1975 he moved to Canada to attend the University of Toronto, where his PH.D. research involved an extensive field study in a deciduous forest on the Canadian shield, under the supervision of Professor F. Ken Hare and the late Professor Geza Szeicz. The data obtained were used to develop physcially based models to explain the snowmelt and evapotranspiration processes in the deciduous forest.

During 1976, he investigated the relationship of climatic change during the Pleistocene to desertification episodes in the major arid/semi-arid areas of the world as part of the background studies for the climatic aspects of the 1977 U.N. Desertification Conference. Also in 1976, he served as a member of a six-man University of Toronto team undertaking an environmental impact assessment of possible actions to alleviate problems associated with a deteriorating dam for the Ontario Ministry of Natural Resources. During 1977-78 he was on attached staff of the Environmental Research Branch of the Chalk River Laboratories of Atomic Energy of Canada Ltd and cooperated in various hydrometeorological research projects.

He moved to Illinois in October 1980 as an associate professional scientist in the climatology and meteorology section of the Illinois State Water Survey. In this capacity he has supervised the establishment, maintenance, and data management and analysis of 18 climatological observing sites around Illinois that were installed to determine the potential of solar radiation and wind as alternative energy sources in addition to measuring the relevant meteorological parameters for agricultural purposes (Solar Weather Program). He is also undertaking research considering the detailed nature of changes in soil moisture profiles with time and is developing a crop water-use model applicable to the Illinois situation and expected to be useful for irrigation scheduling.

He is one of four cooperating scientists recently awarded a grant by the Illinois Department of Energy and Natural Resources to investigate the relationship of the movement of insect pests and weather (Pests and Weather Program). This will include spatial scales from long-range migration to interfield and between-plant movement patterns, and will link these patterns with weather conditions (meso- and micro-scale) and crop growth.

Patrick R. Hughes

Dr. Hughes received his undergraduate training in entomology at San Jose State College and both the M.S. and Ph.D. degrees from the University of California at Davis. In 1967 and 1968 he served as a post-graduate research entomologist in Santiago, Chile, as part of a cooperative program between the University of California and the University of Chile. He joined the Boyce Thompson Institute in 1969 where he was involved in research on pheromones of barb beetles in the U.S., Mexico, and Central America until 1976. In 1977 he was a guest professor at the Forest Zoology Institute of the University of Freiburg in West Germany. Since 1977 his research emphasis at Boyce Thompson has been on the effects of plant stress on the success of phytophagous insects. He is an authority on the effects of air pollutants on plant-insect interactions and is particularly interested in the ways in which low levels of pollutants can change the susceptibility of plants to insect damage.

Dr. Hughes is a member of the Entomological Society of America, the American Registry of Professional Entomologists, the American Society for Virology and the Society for Invertebrate Pathology.

William W. Kellogg

Dr. William W. Kellogg joined the National Center for Atmospheric Research (NCAR) in Boulder, Colorado in 1964 and served for nearly 10 years as director of its Laboratory of Atmospheric Sciences; he is now a senior scientist, working with the NCAR Advanced Study Program. Before joining NCAR he was head of the Planetary Sciences Department of the RAND Corporation in Santa Monica, California, an organization with which he was connected for 17 years.

He obtained a B.A. in physics at Yale University, and an M.A. and Ph.D. in meteorology at UCLA. He served as a pilot-weather officer during World War II, and left the Army Air Force in 1946 with the rank of Captain to resume his graduate studies. From 1950 to 1952 he was an assistant professor in the Institute of Geophysics at UCLA.

He has served on a number of governmental advisory committees, including the Panel on the Environment of the President's Science Advisory Committee, the USAF Scientific Advisory Board, the Department of Commerce Technical Advisory Board, and the NASA Space Program Advisory Council. He has been a member of the National Academy of Sciences' Earth Satellite Panel for the IGY, Space Science Board, Committee on Atmospheric Sciences, and the Polar Research Board. He is a past president of the American Meteorological Society and of the Meteorology Section of the American Geophysical Union, and he is Chairperson-elect of the Atmospheric and Hydrospheric Sciences Section (W) of the American Association for the Advancement of Science. In addition, he has been and is active in a number of international organizations, notably the International Union of Geodesy and Geophysics, the Committee on Space Research and the World Meteorological Organization.

James E. King

James E. King is head of the scientific sections at the Illinois State Museum. He is responsible for planning coordination and administration of the scientific research programs at the Museum and operation of the Museum's laboratory. Dr. King has been with the Museum 11 years and he is also an adjunct associate professor of geology at the University of Illinois, Champaign.

Dr. King holds a B.S. in biology from Alma College and an M.S. in botany from the University of New Mexico, and he received his Ph.D. from the University of Arizona in geology in 1972. His research has been on the paleoenvironments of the past 50,000 years and vegetational adaption in response to climate change from the last period of continental glaciation to the present. Recently, his research has centered on the history of the prairie peninsula as recorded by fossil evidence from a series of sites throughout Illinois. Dr. King has written numerous scientific articles and research reports on vegetation and changing climates.

Helmut E. Landsberg

Helmut E. Landsberg received his Ph.D. in meteorology and geophysics from the University of Frankfurt (Germany). Prior to World War II he taught at both Penn State University and the University of Chicago. He served as operations analyst with the Air Force and after the war was director of the Geophysics Laboratories at the Air Force Cambridge Research Center. Between 1954 and 1966 he served the Weather Bureau and the Environmental Science Services Administration as director of climatology. In 1967 he joined the faculty of the University of Maryland where he established the graduate program in meteorology. In 1976 he became Professor Emeritus and has concentrated on research. He is author of several books and many papers. He is also editor-in-chief of the "World Survey of Climatology." His present research is concentrating on the resurrection of early weather records and their relevance for studies of climatic fluctuations.

Volker A. Mohnen

Volker A. Mohnen has been director of the Atmospheric Sciences Research Center at the State University of New York at Albany since 1975. Prior to that he held positions as acting director (1974-1975) and associate director (1972-1974) of the Center. He was associate professor in the Department of Atmospheric Sciences from 1967 to 1977.

Dr. Mohnen received his B.S. at the University of Karlsruhe (Germany) in 1959, and his M.S. in 1962 and Ph.D. in 1966 from the University of Munich.

He has been a consultant to many agencies and companies in the field of air pollution, aerosol physics and atmospheric sciences, including General Electric, the NASA-Lewis Research Center, the American Petroleum Institute and the Environmental Protection Agency. He has served on numerous scientific and technical committees.

Dr. Mohnen is a Certified Consulting Meteorologist (AMS) and a Fellow of both the American Association for the Advancement of Science and the New York Academy of Science. He is also a member of the American Chemical Society, the American Geophysical Union, the American Physical Society, the Air Pollution Control Association and Deutsche Physikalische Gesellschaft.

Jerry S. Olson

With degrees in philosophy, geology, ecology and botany (1947-1951) and postdoctoral work in statistics at the University of Chicago, and studies in soil science at the University of California, Berkeley (1950), Jerry Olson was pathfinding in complex, interdisciplinary environmental research long before this became fashionable. Physiological ecology work at The Connecticut Agricultural Experiment Station (1952-58) found prompt application in forestry. Experiments and model predictions about ecosystem dynamics and isotopes since he moved to Oak Ridge National Laboratory (1958 to present) opened wide areas of ecosystem analysis there and elsewhere.

Basic "systems ecology" and simulation modeling work were founded there and in part-time teaching at the University of Tennessee Graduate Ecology Program as a professor of biology since 1964. His graduate courses also included Environmental Policy, Environmental Monitoring and Environmental Assessment. Biogeochemical cycles of elements have unified much of this work and led to his current projects on global cycling and models of carbon. Relations of enhanced atmospheric CO_2 to probable climatic change hold many implications about knowledge and uncertainty: concerning ecosystems, society, policy on energy, and research strategy and tactics.

Olson's honors include the Ecological Society of America's George Mercer Award (1958) for his doctoral research on sand dune formation and succession around the Great Lakes; a John Simon Guggenheim Memorial Fellowship (1962-64); and Outstanding Achievement Award (1974) while on leave to the U.S. Atomic Energy Commission during its transformation into the Energy Research and Development Administration (now Department of Energy). He was one of the first Americans involved in the International Biological Program (1963-1974) for the U.S. National Academy of Sciences and has served on numerous National Research Council groups.

William A. Reiners

In summer 1983, William A. Reiners became a professor of botany and head of the Department of Botany at the University of Wyoming, in Laramie. Before this appointment, he was a professor of biological sciences and chairman of the Department of Biological Sciences at Dartmouth College in Hanover, New Hampshire. Dr. Reiners has been associated with Dartmouth College since 1967, except for 1976-77 when he was program director of the Ecosystems Studies Program at the National Science Foundation. Prior to 1867, he was an instructor and assistant professor in botany at the University of Minnesota.

Dr. Reiners received his B.A. in 1959 from Knox College in Galesburg, Illinois. He received his M.S. in 1962 and Ph.D. in 1964 from Rutgers University.

He has extensive teaching experience in biology, botany and ecology. Dr. Reiners is currently working on biogeochemical problems in terrestrial environments, including the deposition of chemical substances to forest canopies and the mechanisms by which forest canopies alter the chemistry of rainwater reaching the ground.

Dr. Reiners has authored numerous professional papers published in scientific journals and presented at scientific meetings. He is a member of the American Association for the Advancement of Science, the British Ecological Society and the Ecological Society of America. He is a member of the Scientific Advisory Committee on SCOPE study of the "Biogeochemical Cycle of Carbon" and a member of the Biosphere Directorate for Project 6 - Study of the Impact of Human Activities on Mountain and Tundra Ecosystems.

William G. Ruesink

William G. Ruesink joined the Illinois Natural History Survey in 1972. After several years of working primarily on a model for the alfalfa weevil, he became leader of the corn insects research team where he directed the development of a black cutworm damage forecasting methodology. Following a year in Australia (1981-1982) where he worked on a model for aphid transmission of barley yellow dwarf disease, he returned to concentrate on modeling European corn borer and aphid transmission of soybean mosaic virus. He also maintains a research program on insect sampling methods.

Stephen H. Schneider

Stephen H. Schneider received his Ph.D. in mechanical engineering and plasma physics from Columbia University in 1971. He then joined the Goddard Institute for Space Studies as a postdoctoral research associate. In 1972 he became a Fellow in the Advanced Study Program at the National Center for Atmospheric Research (NCAR) and in subsequent years was involved in the Climate Program and the Climate Sensitivity Group. In 1980 Schneider was appointed as Senior Scientist at NCAR and became head of the Visitors Program and deputy director of the Advanced Study Program, positions he currently holds.

Dr. Schneider has given testimony to the U.S. House and Senate on environmental, food, water and energy issues. He was a White House consultant for the Nixon and Carter administrations, and a consultant to the U.S. Department of Energy and other federal agencies. He has served on numerous national and international committees on climate, food, water, energy and environmental and societal issues.

He has authored several books and over 80 papers, most dealing with climate, climate change and climate impacts. He has appeared on many radio and television programs, including the MacNeil-Lehrer Report, Nightline, Nova, and the Today Show.

Dr. Schneider is a member of the American Meteorological Society, the American Geophysical Union, the American Association for the Advancement of Science, the Federation of American Scientists, Sigma Xi, the U.S. Association for Club of Rome, the American Academy of Political and Social Science, the New York Academy of Sciences, and is a Fellow, Scientists' Institute for Public Information.

Richard G. Semonin

Richard G. Semonin attended the University of Akron and transferred to the University of Washington completing his B.Sc. in meteorology in 1955. He was employed, upon graduation, by the Illinois State Water Survey as a research assistant and currently is assistant chief for administration and research of the Water Survey and professor of meteorology in the Department of Atmospheric Science of the Graduate College at the University of Illinois.

He has worked in weather radar, cloud physics, weather modification, urban effects on local climate, and atmospheric chemistry. This work has extended from laboratory studies to extensive field measurement projects involving the use of aircraft over large areas and hundreds of meteorological instruments. The various projects have been reported by Professor Semonin in over 100 reports and professional journal papers.

He is a Fellow of the American Meteorological Society and has held various positions both at the national and local levels. Currently, Semonin is a Councilor and chairman of the Committee on Professional Ethics. He is also immediate past-chief editor of the Journal of Applied Meteorology. Professor Semonin is also a Fellow of the American Association for the Advancement of Science. He is a member of the Weather Modification Association and on its Membership Committee, and is a member and past Councilor of the National Weather Association. Professor Semonin is also a member of the Sigma Xi and the Illinois Academy of Sciences.

Semonin servies on the Executive Committee of the National Atmospheric Deposition Program and is past-chairman of the Site Selection and Certification Subcommittee. He is currently a member of the EPA-MAP3S/RAINE Coordination and Review Group. He served on a review team for the National Acid Precipitation Assessment Plan and reviewed, for the Department of Energy, the modeling work on acid rain under the Memorandum of Intent with Canada. Semonin recently served as a team member for review of the federal Interagency Task Force on Acid Precipitation research plan.

Wayne M. Wendland

Wayne M. Wendland attended Lawrence College, Oklahoma State University, and the University of Wisconsin-Madison (Ph.D. 1972). He was a weather officer (USAF) from 1956-1964, serving at several bases. After completion of graduate school, he was appointed an assistant professor in the Departments of Meteorology and Geography at the University of Wisconsin-Madison. He served as visiting associate professor of geography in 1976 and associate professor in 1978, University of Illinois-Urbana. He was appointed as professional scientist at the Water Survey during the summer of 1979 and is currently head of the climatology and meteorology section.

Dr. Wendland's research interests include climatology, paleo- and historical-climatology, and spatial and temporal climatic variability. He has published more than 25 reports and articles in a variety of journals. Dr. Wendland is a member of the American Meteorological Society, American Association for the Advancement of Science, the Association of American Geographers and the American Quaternary Association.

Michael B. Witte

Michael Witte is the director of the Illinois Department of Energy and Natural Resources. This is a cabinet-level department reporting to the Governor of Illinois. His agency is responsible for data collection, research, policy formulation and public education concerning the development and conservation of Illinois' energy and natural resources. The Department includes the state's Geological, Natural History, and Water Surveys, the Illinois State Museum, and the Energy and Environmental Affairs division.

Director Witte is currently chairman of the Board of Natural Resources and Conservation, chairman of the Energy Review Board, chairman of the Illinois Coal Research Board, a member of the Illinois State Museum Board, and chairman of the Governor's Sunset Task Force on Utility Regulatory Reform.

Prior to becoming director, Mr. Witte served as deputy director of ENR. Since January of 1977 he has served in Illinois state government in a number of other management capacities, including assistant director of the Institute of Natural Resources, assistant director of the Division of Energy in the former Department of Business and Economic Development, and manager of the state's energy conservation programs.

Mr. Witte pursued his high school education in Alma, Michigan; his undergraduate training at the University of Michigan; and a masters program at the University of Illinois.

Sylvan H. Wittwer

Sylvan H. Wittwer, director of the Agricultural Experiment Station, associate dean of the College of Agriculture and Natural Resources, and a professor of horticulture at Michigan State University, East Lansing has pioneered in the frontiers of agricultural research since receiving his Ph.D. in 1943 at the University of Missouri. His interests have covered protected cultivation for crops, plant growth regulation, foliar absorption of nutrients, limits of biological productivity for crops and food animals, research and technologies for global food production, and agricultural communications.

He has published over 600 research papers and scientific reports and is in great demand as a keynote speaker. He has traveled extensively as a consultant for international agricultural research centers and has assisted in agricultural development research programs for Kuwait, Korea, Israel, Brazil, Taiwan, India, the Soviet Union, and the People's Republic of China. His participation has included more than 50 international conferences and symposia. He chaired the Board on Agriculture and Renewable Resources for four years and has served on numerous other boards and committees of the National research Council/National Academy of Sciences. He is a member of the Executive Committee and Trustee of the Nutrition Foundation. He has served as a consultant for the National Science Foundation, Resources for the Future, the United States Department of Agriculture, the National Aeronautics and Space Administration and the Department of Energy.

Dr. Wittwer is one of the two Americans elected to the A.I. Lenin All Union Academy of Sciences in the U.S.S.R. and is a recipient of the James E. Talmadge Science Award from Brigham Young University and an Honorary Doctor of Science degree from Utah State University. He was appointed in 1981 to the Science and Technology Advisory Group for the Executive Yuan of the Republic of China.

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BRIEF HISTORY OF THE ILLINOIS DEPARTMENT OF ENERGY AND NATURAL RESOURCES

In March 1978, an executive action initiated the process from which ENR grew. The new agency created by this action was called the Illinois Institute of Energy and Environmental Resources and included the state's energy office – previously part of the Department of Business and Economic Development (BED) – and the Institute for Environmental Quality.

The newborn agency got a new name and added four components following a legislative action in July 1978. This changed the name to the Institute of Natural Resources and added the three scientific surveys and the state museum to the agency ranks. This change reflected the lawmakers' realization that many natural resource issues are inherently interrelated. In order to make wise decisions regarding resource use and management, it is often vital to have a clear understanding of how these resources affect the environment and each other.

In September 1981, Public Act 82-592 changed the Illinois Institute of Natural Resources to the Illinois Department of Energy and Natural Resources. Although the name change did not change ENR's responsibilities, it did acknowledge that more emphasis is being placed on energy resource development and expansion, areas which are becoming increasingly important to the state's well-being.

Today, ENR is composed of five divisions:

Energy and Environmental Affairs. This division conducts applied environmental and economic research intended to guide the state's policy decisions. The division encourages the development of new energy technologies and offers direct services to Illinois residents interested in making more efficient use of energy resources and energy conservation techniques.

Geological Survey. Established in 1851, this division maps the geological formations and mineral resources of the state, then determines their chemical and physical properties. Educational programs are available to schools and the public.

Natural History Survey. Studies on plant and animal resources of the state are the focus of this division, which was established in 1858. Classification of environments and control of insect pests are among the many research activities conducted by the division.

State Museum. The state's natural history, art and anthropological history are collected, preserved and interpreted by this division. Established in 1877, this division displays and prepares exhibits of many historic objects and offers a variety of public educational programs.

Water Survey. This division researches questions on the quantity and quality of atmospheric, surface and underground water resources in Illinois. Studies of water use and conservation, development of water supplies, water resource planning and management and meteorologic factors that affect water resources are prepared and distributed.

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			14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report contains the speeches and papers presented at the 12th Annual ENR Conference, held September 13-14, 1983 on the campus of the University of Illinois at Urbana-Champaign. Also included are biographies of the speakers and a brief history of the Department of Energy and Natural Resources. This conference discussed Illinois' climate over the past 10,000 years up to the present and explored the theories regarding both a warm future climate and a cold future climate. Speakers also examined the effects of air pollution and climate upon insect pests and their movement. The impacts of changes in the carbon dioxide levels upon agriculture and current studies of acid rain issues were also presented. The directors of Illinois' three environmental departments, ENR, Illinois Environmental Protection Agency and Illinois Pollution Control Board, reported on their agencies' efforts in the previously discussed areas.

17. Document Analysis a. Descriptors

Climatic Changes
Paleoclimatology
Carbon Dioxide
Pest Control
Precipitation (Chemistry)
Acid Rain
Illinois

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 04 Atmospheric Sciences/B Meteorology

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